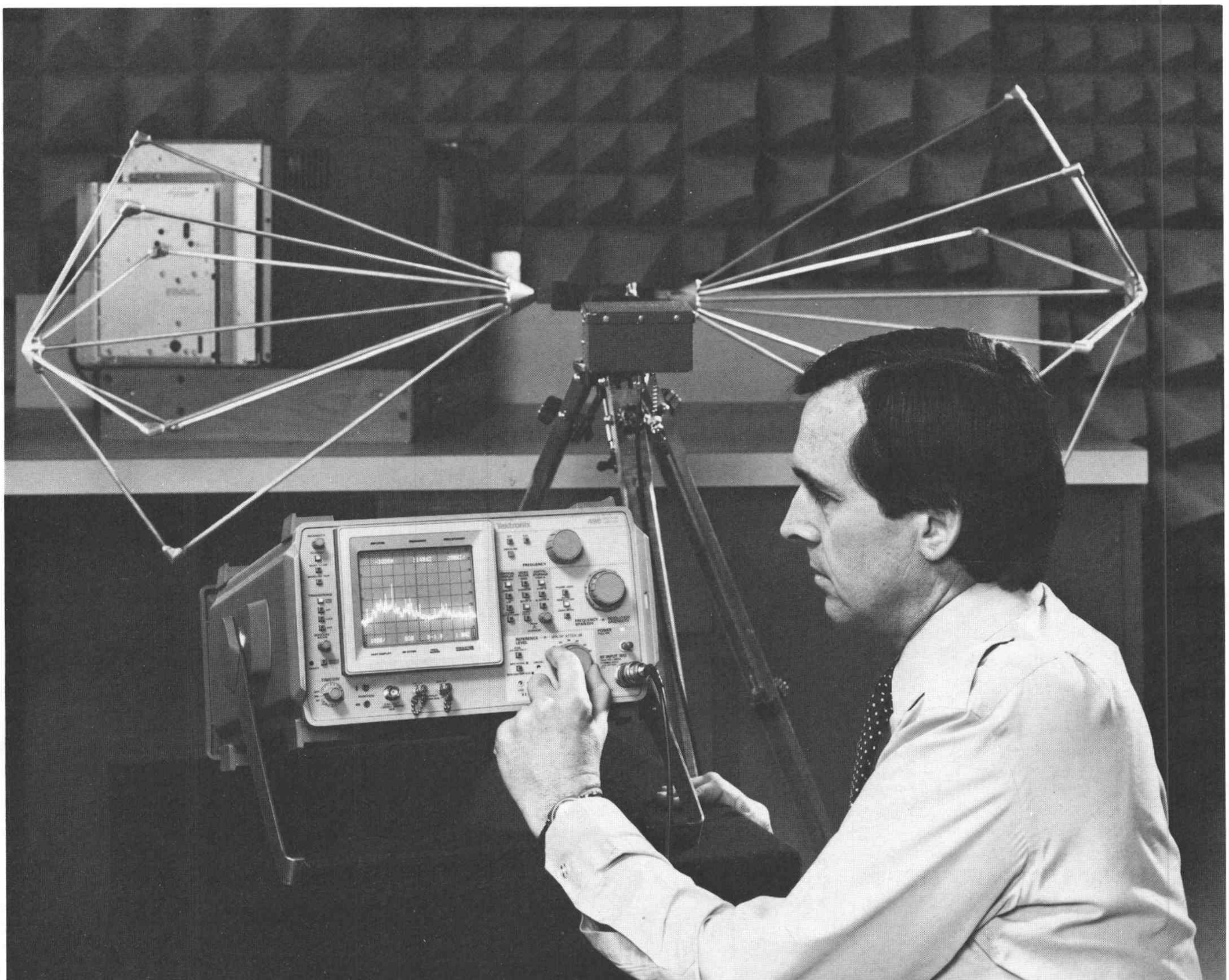
EMI Measurements Using a Spectrum Analyzer



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I. Introduction to EMI Measurements

A U.S. government report begins with "The subject of radio interference measurement has been receiving increased interest in recent years".[1] Many changes have taken place in the years since this report was written in July of 1962; but interest in measuring the interference potential of products remains high. On September 18, 1979 the U.S. Federal Communications Commission adopted new regulations to reduce the interference potential from digital products, including computing devices used both in the home and industry. These new regulations caused sudden interest in EMI (previously called radio frequency interference or RFI) among manufacturers who previously had no experience with the measurement of RF voltages and field strength.

The new rules, Part 15 Subpart J, owes much of its technical content to measures taken years ago in the Common Market countries and elsewhere. To some manufacturers who had been developing products that comply with CISPR (Comite International Special des Perturbations Radioelectriques) and VDE (Verband Deutscher Elektrotechniker), the new U.S. rules are a variation in test methods they already use.

Equipment used to make EMI measurements is more varied today than years ago. Originally the primary measurement apparatus was a receiver with calibrated meter and RF and IF circuits. The spectrum analyzer has emerged over the years as an outgrowth of panoramic display receivers and as a result of radar measurement equipment. Either a modern EMI receiver or spectrum analyzer can be used to make measurements.

[1] *"The Radio Frequency Interference Meter"* published in July 1962 by the Superintendent of Documents (NAVSHIPS 94180)

Many spectrum analyzers and receivers use microprocessor-aided controls to simplify their operation. Spectrum analyzers offer some added convenient features:

- Digital storage of display data along with save and maximum hold features.
- Wide swept frequency coverage to permit displaying as large a range of frequencies as desired to assess the emissions levels at a glance.

A compact, mobile spectrum analyzer makes the measurement convenient in the field or at the designers' work place. At the point of design, resources can be summoned to improve EMI characteristics and evaluate alternate designs. Ease of use makes the measurement simple for the non-RF expert accustomed to digital design tools such as logic analyzers and oscilloscopes. Full programmability allows automatically performing measurement setups that would be difficult for the non-RF expert.

Portability also enables measurements at test sites or equipment installation.

A. Measurements Possible with a Spectrum Analyzer

A spectrum analyzer can be used in a variety of measurements for EMI tests. These include:

- Product testing by the manufacturer for verification or certification under the FCC Rules Part 15 Subpart J.
- Testing prior to submission to a certified test station for VDE or CISPR requirements.
- Testing in design for evaluaton of EMI control measures or to evaluate the effects of design changes on EMI performance.
- Test site measurements such as site attenuation and measurement of ambient levels prior to testing or site selection and construction.

EMI Measurements Using a Spectrum Analyzer was written by Dave Barnard, Frequency Domain Instruments Marketing staff member.

B. Why Digital Products are Sources of EMI

New U.S. and other regulations impose EMI requirements not only on computing devices but any products that use clock frequencies above 10 kHz and digital techniques. The reason the FCC adopted new regulations was to place limits on products that generate a lot of RF as a consequence of their design. Although not intentionally, digital techniques provide signals rich in high-frequency components. The key ingredient in digital computing is accurate timing of information in step with a clock to maintain the required speed and accuracy. To maintain timing accuracy and keep logic elements out of the linear region, fast, well-defined transitions are required. Well-defined rise and fall times and narrow width (low duty factor) pulses provide energy dispersion like that found in pulsed microwave signals (common to radar equipment). Except for a carrier frequency at dc (0 Hz) digital signals have similar spectral shape. For example, the signal in Figure 1-1 is derived from a 20 MHz clock.

It is a typical waveform that might be used for gating information for transfer. It has a lower (than the raw clock) fundamental frequency. The frequency domain display of this same signal (Figure 1-2) shows it to contain numerous components at multiples of the fundamental. It spreads its energy over a broad range by having a lower on-to-off ratio. This is what would be expected by Fourier analysis of this waveshape. However the theoretical analysis would be time consuming and difficult for any real waveshape. A fast Fourier Transform method could also be used but is limited in frequency range and speed. The display of the spectrum analyzer shows the energy at all frequencies in the range and unlike FFT techniques covers the range by a continuous sweep rather than in discrete sample steps.

In a product such as a home computer, the source of EMI would be an ensemble of pulsed waveforms of varying width, and with rise and fall transitions more or less in synchronism with a basic clock. All of these would be potentially coupled or radiated by mechanisms that tend to be high pass in nature. The effect of stray capacitance or the natural tendency to radiate increases as frequency increases. Circuit paths that look straightforward at dc may prove to be resonant at frequencies in the hundreds of MHz where significant harmonics of the digital waveform exist.[2]

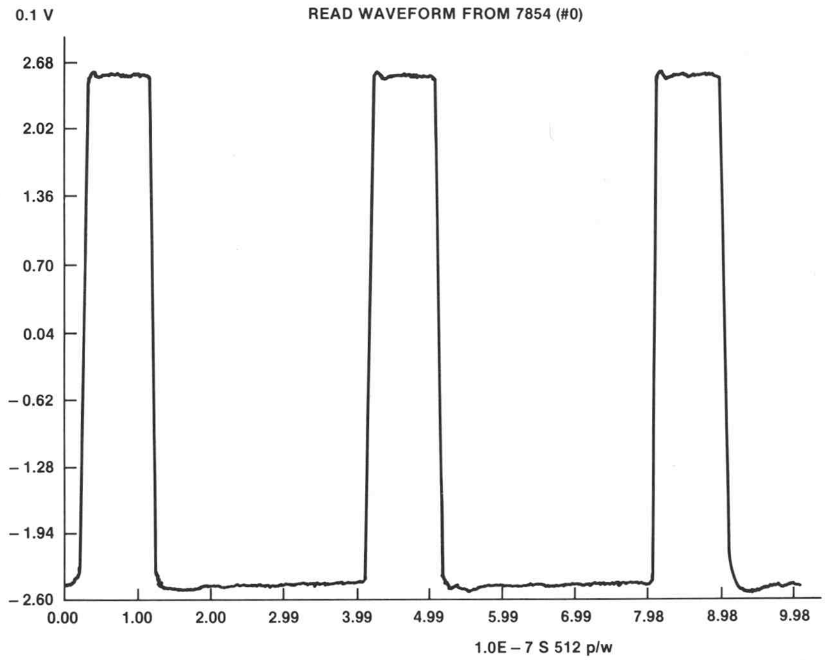


Figure 1-1. 20 MHz divided by 8.

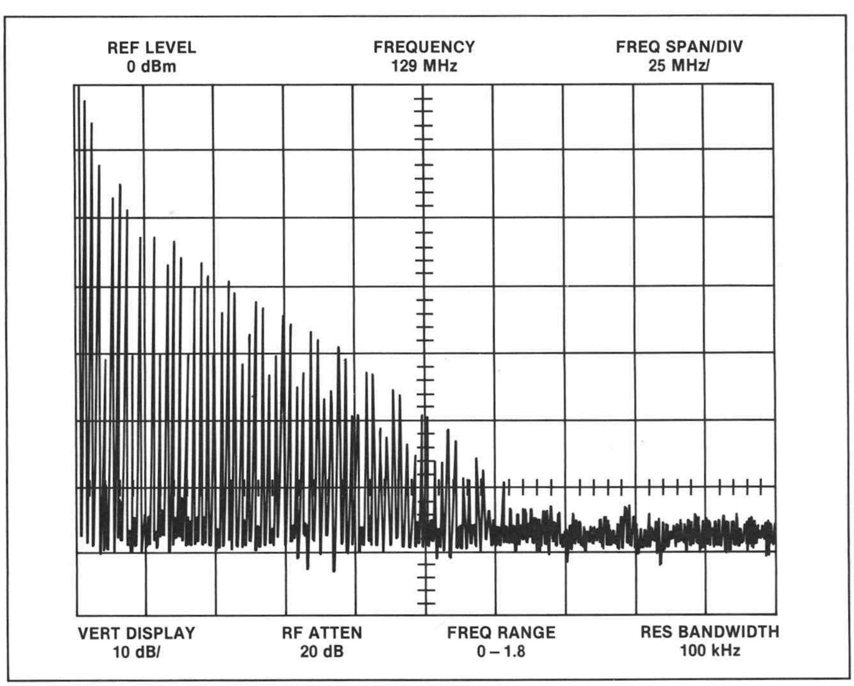


Figure 1-2. Waveform of Figure 1-1 shown on a spectrum analyzer.

The RF producing potential of a product is hard to assess theoretically. A spectrum analyzer used at the designers' area can provide a means of surveying the design before it is frozen. As a result, test time and expense can be saved.

[2] *"Circuit Grounding and Shielding Designs For Suppressing Electromagnetic Emissions",* Edwin L. Bronaugh, Session 5, 1980 Midcon Professional Program, November 1980.

C. Interference Paths

There are two ways that radio frequency energy can travel from a source (Figure 1-3) to a potential victim of interference:

- Radiation — in the form of electromagnetic waves directly from the equipment and associated power cord (if used).
- Conduction — transmission through the connecting power cord to the power mains where it travels directly to another device or may be radiated by the power mains.

Tests of radiated emissions require an antenna connected to the spectrum analyzer. These are field strength measurements that measure voltage developed by the antenna and compare it to field intensity (volts per meter) by converting volts to volts per meter via an antenna factor. Test limits are specified at a defined distance, over a well-controlled propagation path. When tests are performed, the associated power and other cables are included as they would be found at a typical user's installation.

Conducted emissions tests use a special type of sensing device to measure the RF voltage imposed on the power cord. While power

systems are well defined at power frequencies they are less well defined at RF frequencies. For test purposes, the equipment is connected to a LISN (Line Impedance Stabilization Network). The spectrum analyzer is connected to the LISN output to measure voltage versus frequency. For example, a LISN stabilizes the impedance at 50 ohms for FCC Part 15 tests. Testing done per CISPR and VDE use other LISN circuits that provide an impedance of 150 ohms. Both versions of conducted emissions tests measure voltage up to a frequency of 30 MHz.

The lower frequency limit for conducted tests extends down to 10 kHz for VDE methods but only down to 450 kHz for FCC Rules Part 15 Subpart J. Radiated measurements required by FCC methods extend from 30 MHz to 1000 MHz. VDE requires testing over the range of 10 kHz to 1000 MHz.

D. Wideband vs. Narrowband Signals

To practicing EMI engineers, the new FCC rules and CISPR or VDE measurement methods are in a distinct class apart from long established MIL-STD 461, 462, 463 test methods. The military methods and limits contain separate levels for narrowband and broadband emissions. The FCC rules only partially distinguish the two signal types in conducted measurements (this is covered in more detail later). For measurements to determine compliance to VDE or CISPR, it is useful also to consider these signal types differently. When using a spectrum analyzer to evaluate a product for compliance to VDE, measured values will depend on the actual bandwidth used to measure broadband emissions. These readings can be corrected by a bandwidth factor to predict the levels found on a CISPR type EMI receiver. For narrowband signals, the levels will be identical unless the signals are related by some process such as amplitude modulation.

In general, to decide which are narrowband and which are broadband, use the rule that if narrowing the resolution bandwidth does not produce more discernible separate peaks, it is a broadband signal. A wideband signal cannot be completely contained within the filter response curve (Figure 1-4) while a narrowband signal will be (Figure 1-5). If the signal is very wide it will have the appearance shown (Figure 1-6), and narrowing the resolution will cause the signal voltage level to decrease about 20 dB per decade of bandwidth reduction.

Another useful technique to aid signal recognition is to connect a speaker-amplifier or headphone to the detector (vertical) output of the spectrum analyzer (with digital storage off). With the detector output converted to audible sounds, noise or pulsing cw signals, or broadcast signals are distinguishable.

E. Peak vs. Quasi-peak

Quasi-peak has its origin in CISPR methods and is based on the psychological effect of interference. Subjectively, bursts of noise received by a broadcast listener's receiver are more annoying as their repetition rate increases. More frequently occurring low-energy bursts are as annoying as higher energy less frequent ones. This concept leads to a detector circuit (Figure 1-7) that performs a weighting operation based on repetition rate. This circuit has specified charge and discharge time constants. A spectrum analyzer, on the other hand, provides peak detection. Peak values can be correlated to quasi-peak levels if care is taken to determine the repetition rate. The spectrum analyzer and EMI receiver will give identical readings above a certain repetition rate depending on quasi-peak bandwidth specified

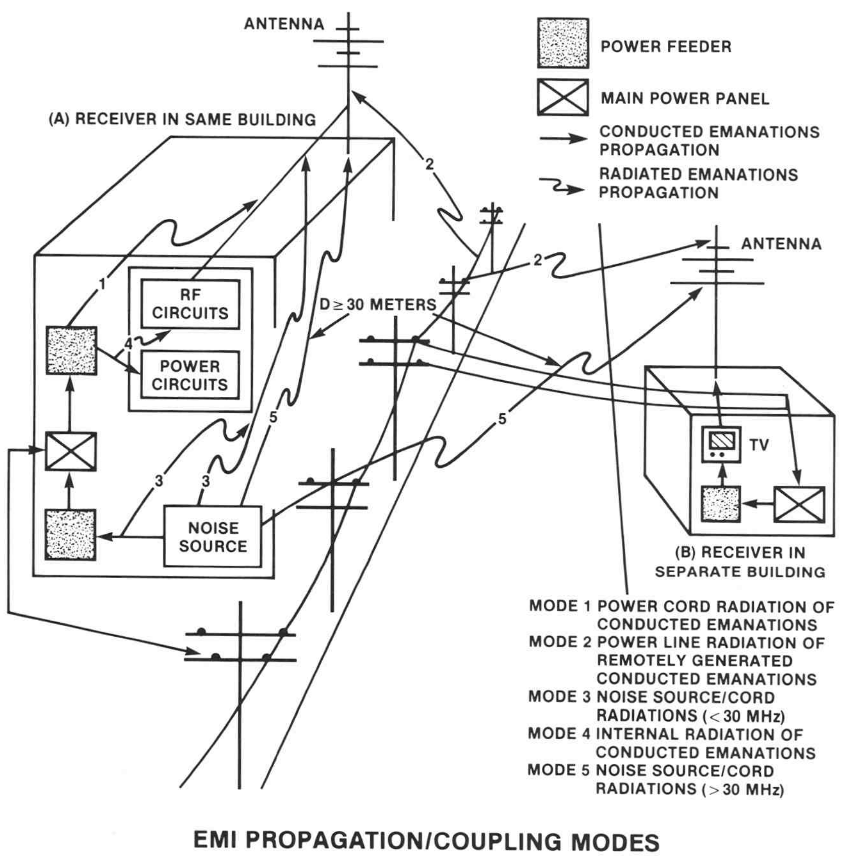


Figure 1-3. EMI is conveyed by conduction, radiation or both to a victim receiver.

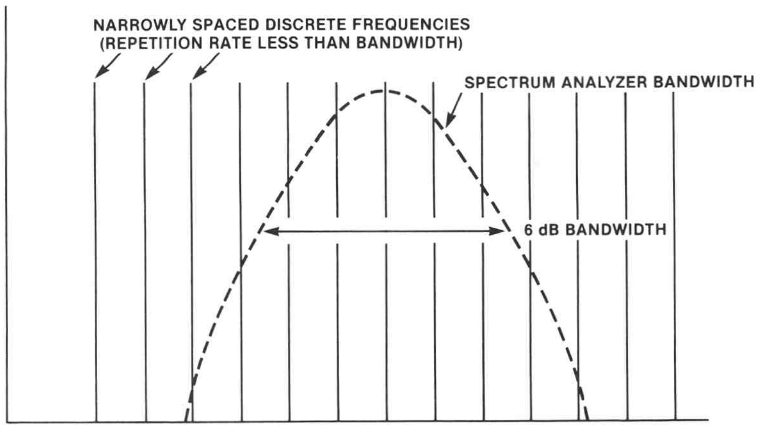


Figure 1-4. A broadband signal composed of narrowly spaced spectral lines cannot be resolved into individual components at the specified measurement bandwidth.

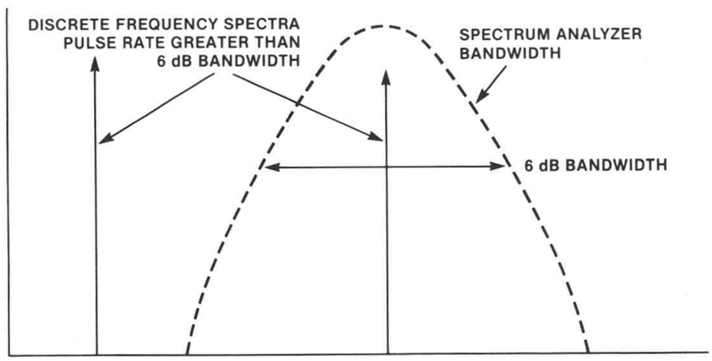


Figure 1-5. Widely separated spectral components can be separated and measured individually.

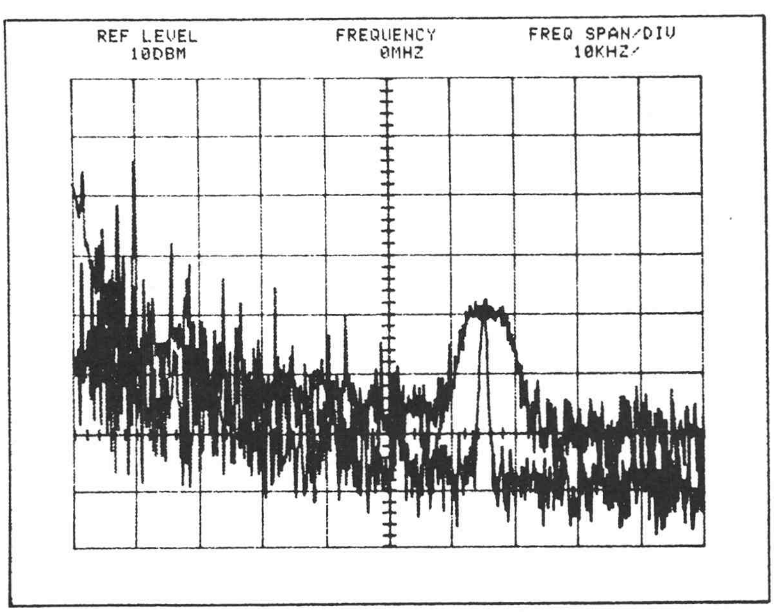


Figure 1-6. Narrowing the resolution bandwidth may not reveal the individual spectral lines, but will cause the observed level to change 10 dB or more. Top trace is in 1 kHz, bottom is 100 Hz bandwidth.

for the measurement. The time constants of the quasi-peak detector require the spectrum analyzer or receiver to dwell at each frequency long enough to allow the circuit to reach its final value. Quasi-peak detectors give the results in simple weighted form but require slower scan rates than peak detectors. Using a peak detector may give higher values than quasi-peak but permits more rapid evaluation of EMI levels.

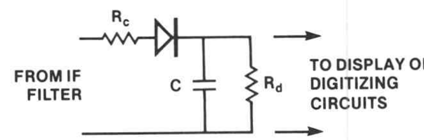


Figure 1-7. A quasi-peak detector has defined charge and discharge times. By allowing the detector to discharge between pulses, low repetition rate bursts are in effect discounted more as rates become lower. A peak holding circuit would simply record the peak level — this is generally the case with spectrum analyzers.

II. Spectrum Analyzer Calibration and Preliminary Measurements

This section contains commonly used procedures that are needed prior to, and during, EMI measurements. The procedures are based on Tektronix 492 and 496 spectrum analyzers, but are similar to those for the Tek 7L14, 7L12 and 7L5. Included are:

Amplitude and Frequency Calibration

Impulse Bandwidth Measurement

Overload Detection

Sensitivity Tests

Some of these procedures are needed only occasionally. Others, such as the test for front end

overload, are useful anytime there is a reason to suspect that overload is occurring. The need for determining the bandwidth will very clearly become evident later when measurements must be corrected for different bandwidths and when peak measurements are converted to equivalent quasi-peak values. Since the bandwidth is established in the spectrum analyzer with crystal filters to within ±20%, this measurement will determine the working bandwidth to closer than 20% and will not have to be remeasured frequently. It will not change unless the resolution bandwidth circuitry in the spectrum analyzer is replaced or repaired.

Knowing the sensitivity helps determine the ability to make some measurements when using antennas that capture less of the incident field and deliver a smaller measurable voltage to the 50 ohm input of the spectrum analyzer.

Frequency and amplitude accuracy need to be verified since they are the primary measurements. FCC Rules Part 15 Appendix A paragraph 4.2.1 require that calibration be checked often enough to ensure accuracy.

A. Amplitude Calibration

If you are using a fully programmable spectrum analyzer, for example, a 492P or 496P with a controller such as Tektronix 4052A or 4041, the program in the automated measurements section will be preferable. Manual amplitude calibration procedures are given in the spectrum analyzer operators's manual.

B. Frequency Calibration

The procedures described here will be useful in verifying the spectrum-analyzer center-frequency readout.

For low frequency measurements the zero frequency or start signal provides a useful frequency reference point. The zero frequency marker is present even when maximum RF attenuation is inserted or when no signals are applied to the RF input of the spectrum analyzer. This signal is the result of the first local oscillator in the analyzer coinciding with the frequency of the first intermediate frequency of the analyzer. The zero mark is the true zero frequency point.

Signals to the right of it are higher than zero Hertz by an amount equal to their frequency. By positioning the zero frequency mark at the proper position on the display, the frequency range can be set with the span per division for accurate readout at low frequencies.

For example, to set the center frequency to exactly 10 MHz, set the span per division to 2 MHz. When the center frequency is 10 MHz, the zero marker will line up with the left vertical graticule line of the display (Figure 2-1). Under program control, other spans per division are possible. For example, with the center frequency at 15 MHz and span per division set to 3 MHz (only possible under program control) and with the zero marker at the left edge, the analyzer will cover the entire range from zero to 30 MHz required for FCC Part 15 conducted emissions. This will enable an overview of EMI performance. Actual and more detailed measurements will require sweeping the range in narrow segments.

If the center frequency seems to differ from that expected, press DEGAUSS when in spans 1 MHz or greater. When the display returns to normal, readjust the tuning knob for proper display, then depress the FR CAL button and rotate the frequency knob until the readout just reaches the proper number. Depress FR CAL again to leave the mode. Additionally the 496 in the DELTA frequency mode indicates offsets from 1 kHz to 1500 kHz with the analyzer in spans of 50 kHz or less.

For higher frequencies, the built-in 100 MHz calibrator or other oscillator of known accuracy may be used.

A pad and tee may be used to make the signal source available without disconnecting the normal signal source such as the LISN or

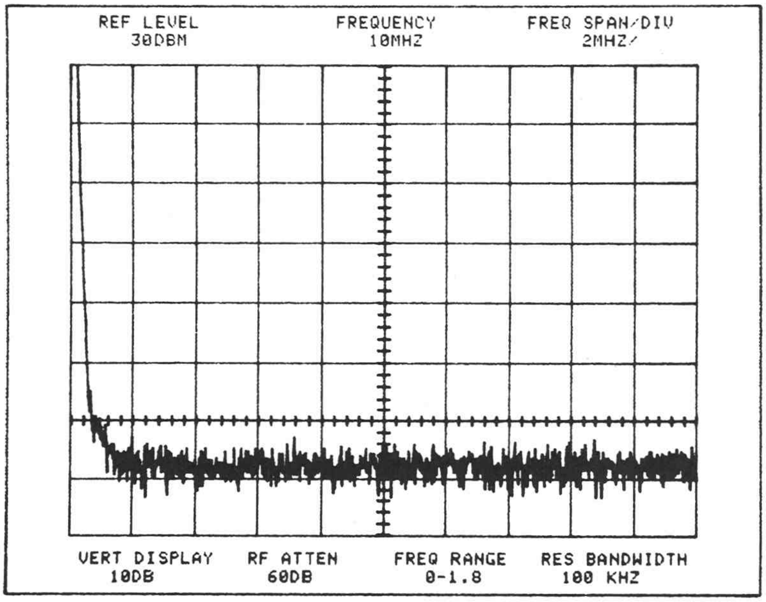


Figure 2-1. The zero frequency peak can be used to accurately set the center frequency to span the desired range. Here it is used to encompass the range of 0 to 20 MHz by using a span of 2 MHz/DIV and by placing the zero mark at the left edge.

antenna. When the calibrator source is not needed, it may be disconnected or its output turned off (as with FG5010 for example).

C. Detecting Mixer Overload

Overload is not a characteristic unique to spectrum analyzers. The phenomenon of overload results from input signals strong enough to exceed the normal operating range of the input mixer. When this occurs, displayed amplitude will not change proportionately with input level. In addition, frequency components not present in the input will be generated, and they will increase 2 or 3 times more rapidly than the input level. Figure 2-2 depicts this graphically. A more detailed discussion of mixer phenomena is available in various texts.[3]

The most frequently encountered EMI measurement situations where overload may occur are when:

- Making conducted measurements. The line frequency (60 Hz) signal as well as high frequency switching power supply signals are significant.
- Making measurements in the vicinity of local broadcast or other communication services, particularly if an external preamplifier is used with antennas.

The importance of overload detection can best be illustrated by example. Suppose a DUT (device under test) contains a high frequency power supply. A strong fundamental at 40 kHz is over driving the analyzer (Figure 2-3). Even though the frequency range scanned is above the fundamental frequency it is generating harmonics not present in the input (Figure 2-4). Ultimately, this unit might pass once the effect of the fundamental is reduced.

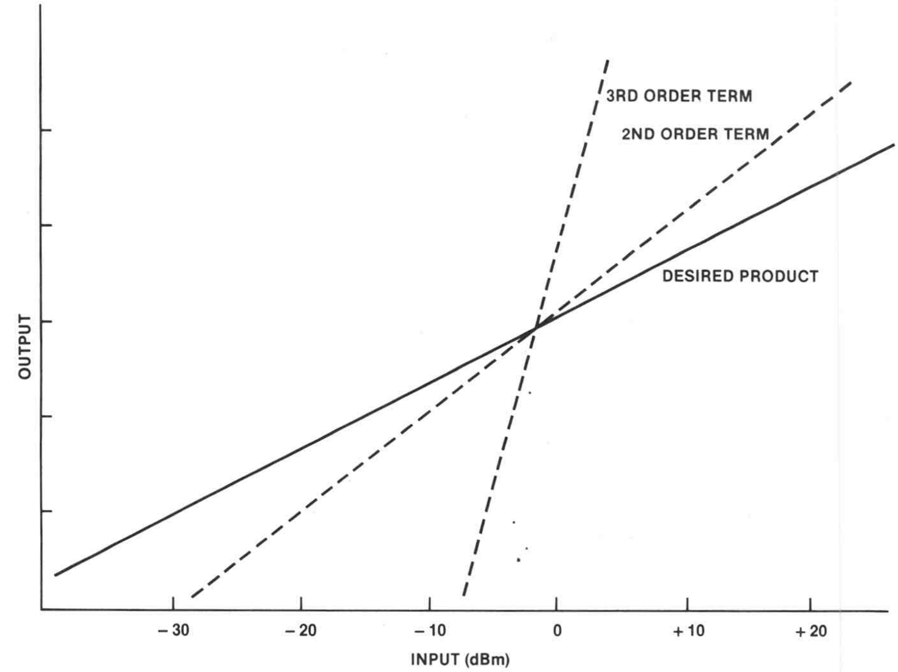


Figure 2-2. Mixers are non-linear because they create frequency components not present in their input. However the ideal mixer would provide only the sum and difference terms. Actual mixers produce higher order terms resulting in spurious signals as shown in the graph of output versus input.

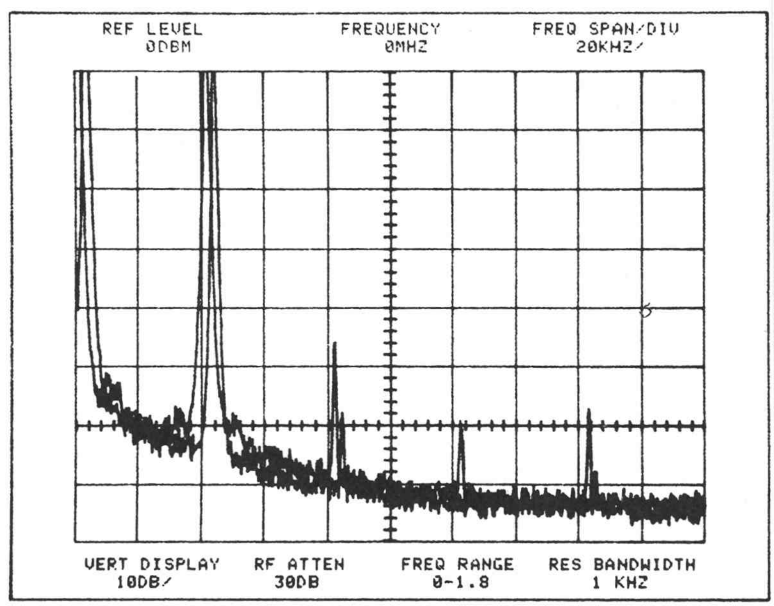


Figure 2-3. With the fundamental (2 divisions from left edge) in view it is easy to determine when it overdrives the spectrum analyzer. Lower trace is with 10 db attenuation.

[3] *"Introduction to Radio Frequency Design"*, W.H. Hayward, Prentice Hall, Englewood Cliffs, N.J.; 1982. Chapter 6 discusses ideal versus practical amplifier and mixer performance.

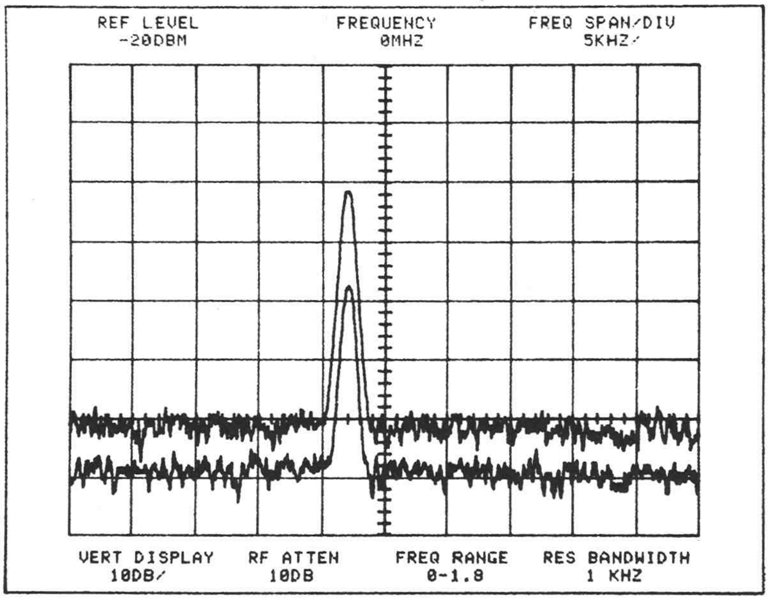


Figure 2-4. When the fundamental cannot be seen it still affects the measurement. Decreasing RF attenuation caused more than a 10 dB increase in this signal. This measurement would be invalid.

To reduce the effects of overload or eliminate them, insert additional RF attenuation between the signal source and the spectrum analyzer. This may be done in two ways:

- Insert a 10 dB attenuator external to the spectrum analyzer — at the input.
- Switch in additional attenuation internally to the 492 or 496. This can be done by rotating the MIN ATN knob clockwise until an additional 10 dB of attenuation is switched in.

With each additional step of 10 dB attenuation the spurious signals will be reduced by more than 10 dB (typically 20 dB or more). If you are viewing the fundamental, it may have decreased by less than 10 dB.

This technique can be used whenever overload is suspected.

D. Sensitivity Testing

To measure sensitivity:

Set the front panel controls to:

VERTICAL DISPLAY: 10 dB/DIV

MINIMUM RF ATTENUATION: 0 dB

FREQUENCY SPAN/DIVISION: 10 kHz

DIGITAL STORAGE: VIEW A and VIEW B on

PEAK/AVERAGE CURSOR: Top of screen

CENTER FREQUENCY: Any in 30 MHz to 1 GHz range

REFERENCE LEVEL: – 40 dBm

TIME: 0.5 sec/DIV

VIDEO FILTER: Wide.

Start with the resolution bandwidth in the 1 MHz position. Decrease the resolution bandwidth and note that the noise level drops 10 dB for each decade of bandwidth reduction (Figure 2-5).

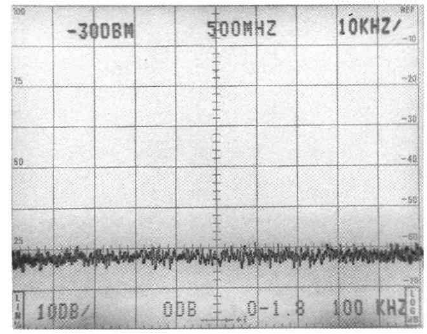


Figure 2-5. This display shows the average noise level in 100 kHz. Video filter is in wide mode.

E. Measuring Spectrum Analyzer Bandwidth

The RESOLUTION BANDWIDTH control of the spectrum analyzer determines its ability to separately display one signal closely spaced in frequency from another. Often, EMI limits are expressed in terms of a specified bandwidth for testing. Other bandwidths can be selected to determine if emissions are closely spaced, resolvable narrowband emissions or broadband. The determination is useful for engineering evaluation of EMI sources in the product being tested.

Spectrum analyzer bandwidth settings are specified to be within 20% of published widths. Once the actual bandwidth is measured for your analyzer, it will be known to an accuracy of 5% (or better). Unless the bandwidth filters are replaced, the measurement won't have to be repeated. The simplest measurement is the 6 dB static bandwidth.

To measure the 6 dB (½ voltage) bandwidth, tune in a narrowband signal from the internal calibrator. Adjust the reference level to place the signal near the top of the screen. Adjust the span per division to spread the signal so that accurate measurements can be made. The 2 dB per division display mode should be used to measure the 6 dB width of the signal in each of the bandwidth selections possible (Figure 2-6).

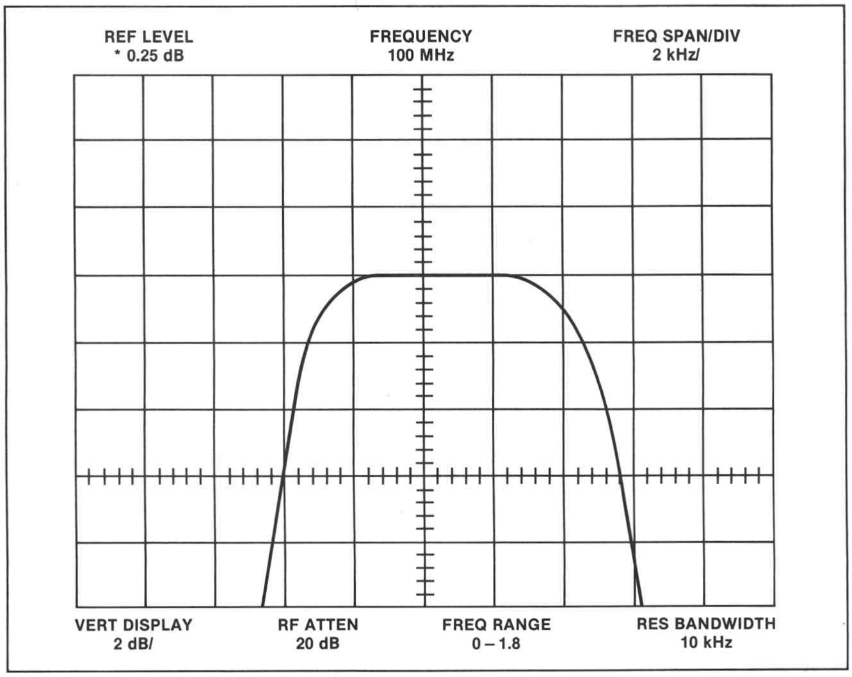


Figure 2-6. By using the DELTA dB mode, and 2 dB per division the top of the filter response can be positioned to simplify 6 dB filter width measurement.

Although literature often refers to other bandwidths, such as the noise bandwidth and impulse bandwidth, the complexities of these measurements often outweigh the gains in accuracy.

A discussion of other bandwidths and definitions can be found in IEC Specification 714 *"Expression of the Properties of Spectrum Analyzers"*. Additional information — including a theoretical discussion — may be found in the Tektronix application note *"Noise Measurements Using the Spectrum Analyzer - Part Two: Impulse Noise"* (AX-3259-1).

The difference between 6 dB and carefully measured impulse bandwidth may contribute up to 2 dB of uncertainty.

III. Units Conversion, Antenna Factors, and Distance Correction

Measured values frequently must be converted or correlated to test limits. This is needed when:

- Converting measurements made in dBm (normal spectrum analyzer display) to volts, microvolts, or dBμV.
- Converting measurements to μV/meter — the units used for electromagnetic radiation.
- Converting radiated emissions measurements made at a test distance (usually closer) to levels corresponding to distances specified by the FCC or other regulatory agency.

Conversions are simple, although they seem awkward at first. If your testing is done with a 492P or 496P, the computer controlling the measurement can do the arithmetic for you.

A. Conversion to μV or dBμV

Conversion from dBm units shown on a spectrum analyzer display is based on simple definition of the logarithm, and power.

Voltage is given by the equation

$$V = .0316 \sqrt{R_0} \sqrt{10^{\frac{P_{dBm}}{10}}}$$

or for $R_0 = 50$ ohms

$$V = .2236 \sqrt{10^{\frac{P_{dBm}}{10}}}$$

Similarly, measurements can be converted to or from dBm and dBμV. To convert from dBm (power relative to a milliwatt) use:

$$dB\mu V = dBm + 107$$

$$\text{or } dBm = dB\mu V - 107$$

B. Conversion to V/Meter

Radiated measurements can be made with a variety of antennas although final testing is preferred using tuned dipoles. The antenna develops a terminal voltage in response to the incident electromagnetic wave.

Converting the voltage readings (or dBm) back to the test limits requires knowing the antenna factor for the particular antennas and frequency of measurement.

The incident field in dBμV/m (relative to a microvolt) is related to antenna voltage by:

$$V\ dB\mu V/m = V(dB\mu V) - K$$

The term K, antenna factor, is a function of frequency and antenna gain.

$$K = 20 \log f(MHz) - GdB - 29.78 \quad \text{(50 ohm system)}$$

$$\text{or } K = 20 \log f(MHz) - GdB - 31.54 \quad \text{(75 ohm system)}$$

G is the power gain of the antenna. An "ideal" non-directional antenna that behaves like a point source radiator is the isotropic radiator with zero gain. Although a theoretical device, practical antennas have been devised that come close to this ideal (see NBS

Technical Note)[4]. In practice, dipoles or other more directional antennas are used. Antenna gain will change with frequency also. When an antenna is purchased, it should be calibrated and an antenna factor curve furnished with it. A typical graph is shown below for antenna factor versus frequency (Figure 3-1).

If measurements are being made with an automated system, the antenna factor can be used in the measurement program to automatically perform conversions.

Combining the conversion:

$$dBm = VdB\mu V/m + K - 107$$

$$\text{or } dB\mu V/m = dBm + 107 - K$$

[4] NBS Technical Note 1033 *"Design and Calibration of the NBS Isotropic Electric-Field Monitor (EFM-5), 0.2 to 1000 MHz".*

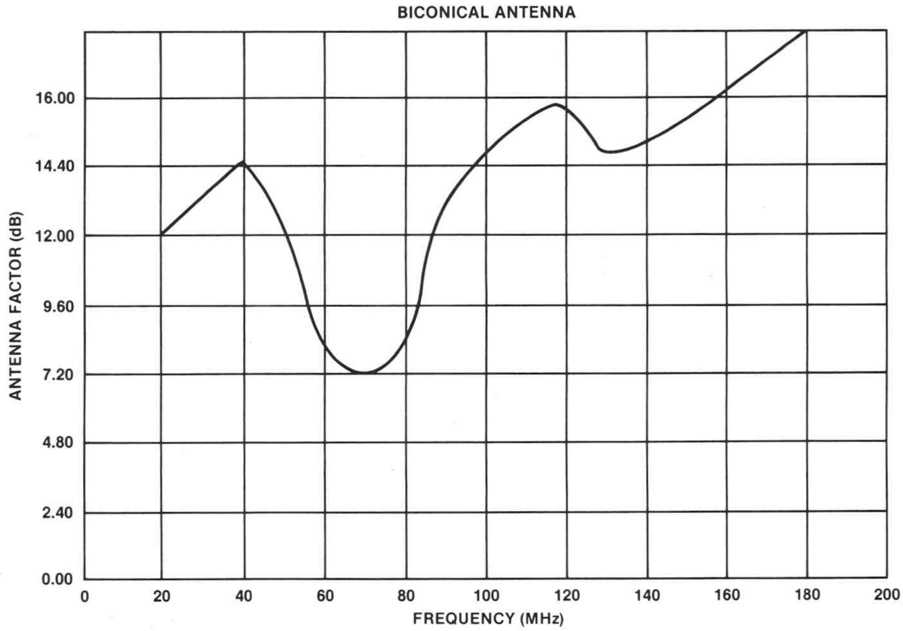


Figure 3-1. Antenna correction factor curves are required for field strength measurement. By using a 4052A, as shown here, data can be displayed, corrected, and used in automated measurements.

C. Distance Correction

Often measurements need to be made with antennas closer than the specified test distance. The advantage is in raising the signal level higher to overcome ambient signals (such as broadcast) or to improve the ability to diagnose the source of the signals (to later apply engineering correction).

Field intensity will vary with distance. Power delivered to the antenna will vary as

$$P \sim \left(\frac{1}{D}\right)^2$$

$$D = \text{distance}$$

Measured power at the test-limit's required distance, P_l relates to the actual power (P_{test}) by:

$$P_l = P_t\left(\frac{D_t}{D_l}\right)^2$$

When testing is done at 3 meters instead of 30 meters (specified for Part 15 Class A), the reported readings must be adjusted by the correction factor given. In logarithmic terms this is

$$\text{adjustment in dB} =$$

$$20 \log\left(\frac{D_t}{D_l}\right) = 20 \log\left(\frac{30}{3}\right) = 20 \text{ dB}$$

When using the distance correction be careful to consider the presence of reflective objects and whether the assumptions of the correction are valid. These calculations assume that measurements are made in the so-called far-field region. Far field conditions are those where power diminishes as the inverse square of measurement distance. This is true when the distance of the measurements is

$$D \geq \frac{300}{2\pi F_{MHz}}$$

For example when performing tests for FCC Part 15 Subpart J at a frequency of 30 MHz we can test whether the 3 meter distance is far-field. The calculations below show that the distance requirement is met beyond a distance of 1.59 meters. Antennas have an effective viewing aperture. When this aperture is large compared to the distance, the distance for far field must be greater. To offset antenna area effects the test recommended minimum distance is 3 meters.

$$D = \frac{300}{2\pi(30)} = \frac{10}{2\pi} = 1.59 \text{ meters}$$

IV. Testing for Compliance with FCC Rules Part 15 Subpart J

Whether you are performing quantitative tests to satisfy technical requirements for verification or certification or performing qualitative measurements prior to submitting the equipment to an outside testing agency, the spectrum analyzer will make the job easier. Especially useful is the analyzer's display covering the entire range of frequencies of interest. Often the maximum emission in one mode or orientation is not at the same frequency as another. A spectrum analyzer can simplify this complicated testing. The byword of testing is to obtain the worst case that can be expected. For Class A equipment testing is

done independently of the FCC and test results submitted. For Class B, with its more stringent limits, a test sample is submitted for testing. Even for Class A equipment the FCC reserves the right to test a sample at random, and is certain to do so if a complaint of interference occurs. When these tests are made they will be done as an audit of your testing and will employ expertise in maximizing the levels detected.

Although much can be done using a spectrum analyzer without digital storage, digital storage is useful because it can simplify some of the procedures needed to maximize levels and perform comparisons. One surprising advantage of the digital storage feature is that it can be disabled revealing more detail of the incoming signals. Digital storage will help when:

- Storing the maximum levels in peak (PEAK/AVERAGE cursor at the bottom) of the screen and activating MAX HOLD. This way transient or slow repetition rate signals won't be missed.
- Using MAX HOLD to save the maximum readings while changing equipment operating modes and position.
- Using split screen display mode (both A and B waveforms visible) to compare MAX HOLD levels with current incoming levels to return to a previously obtained maximum value.
- Comparing MAX HOLD values of peak signals with averaged values to differentiate narrowband from broadband signals.

The use of digital storage will be illustrated by example throughout this discussion. A theoretical discussion is contained in another Application Note — *"Noise Measurements Using The Spectrum Analyzer Part One: Random Noise"* (AX-3260, published by Tektronix, Inc.).

A. Conducted Emissions Tests

Initially, testing should begin with conducted measurements using the equipment arranged as shown (Figure 4-1)[5]. Signals detected during conducted measurements may be accompanied by harmonics that will fall in the 30 to 1000 MHz range. When radiated emissions tests are later performed the power cord will act as an antenna radiating signals conducted onto it. Testing and corrective action for conducted limits can thwart problems that may later arise in meeting radiated emissions limits.

[5] *"Testing Products Correctly Ensures EMI-Spec Compliance"*, Isador Straus, EDN, November 25, 1981.

Using the 50 ohm 50 microhenry LISN establishes a well-defined impedance for signals conducted to the power (mains) cable as shown (Figures 4-2 and 4-3). When a signal port on the LISN is unused it should be terminated with a 50 ohm load. Several accessories available from Tektronix may serve this purpose: a 50 ohm feedthrough terminator (part number 011-0049-01) or a 50 ohm 10X (20 dB) attenuator (part number 011-0059-02).

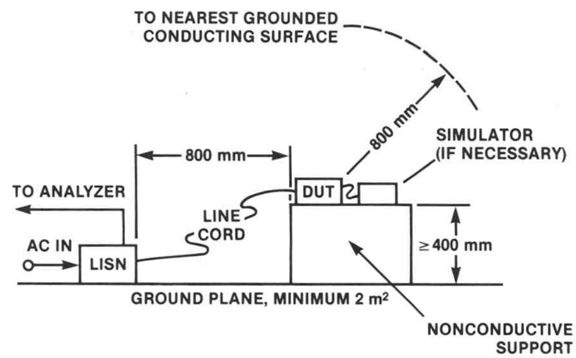


Figure 4-1. Although conducted measurements are essentially in a closed system — in coax, some care is used to minimize coupling effects due to parasitic capacitance and inductance. The arrangement shown does this, and keeps the measurement area to a minimum.

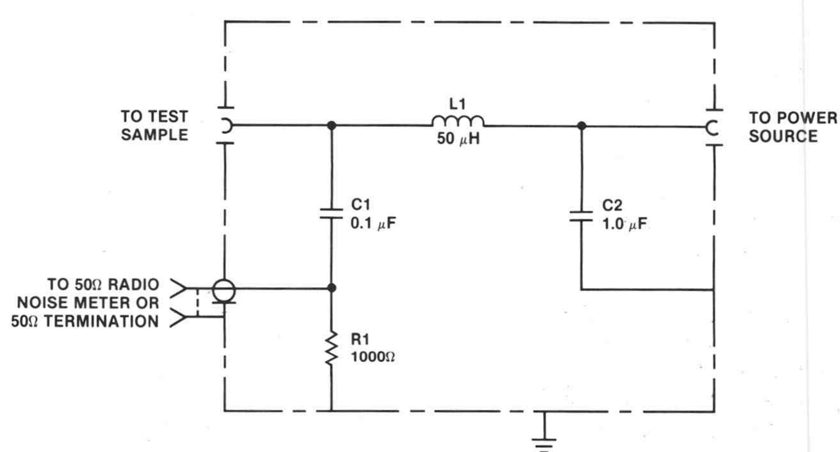


Figure 4-2. Circuit diagram of LISN to provide impedance of Figure 4-3 for the 0.45 - 30 MHz frequency range.

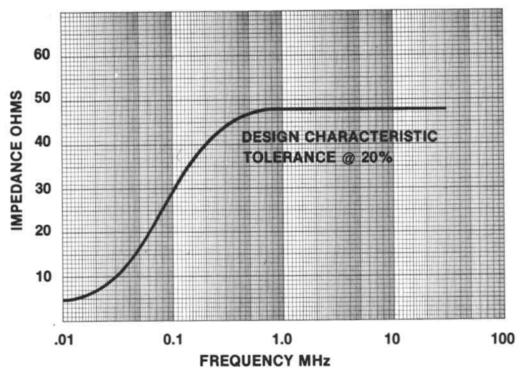


Figure 4-3. Impedance characteristic of line impedance stabilization network (10 kHz to 30 MHz).

Before connecting the spectrum analyzer to the LISN energize the equipment and place it into its normal operating mode. By doing this before connecting the analyzer, the likelihood of encountering power-on transients that could damage the spectrum analyzer input circuitry is minimized. The measurement procedure that can be used is the following:

- Begin with the maximum attenuator setting of the spectrum analyzer. The 492, 492P, 496, and 496P all assume this mode on power up. Additionally programmable analyzers assume this condition as a result of executing an ''INIT'' or ''MAX POWER'' command.
- Scan the frequency range from 0.45 to 30 MHz by setting the CENTER FREQUENCY and SPAN PER DIVISION controls.
- Reduce the RF attenuation 10 dB at a time until signals are discernible.
- Operate the device under test in a variety of modes using its front panel controls or if it is a computing device, use diagnostic programs.
- While the device is operating in various modes use the MAX HOLD mode of digital storage to obtain the largest readings for the frequency range. Take note of at least the six largest signal frequencies. These can be examined later in more detail.
- For purposes of comparison with FCC Part 15 Subpart J make the measurements using a resolution bandwidth of no less than 10 kHz (the 492, 492P, 496, and 496P have this resolution bandwidth setting available).
- To obtain peak levels be certain that the PEAK/AVERAGE cursor is positioned at the bottom of the display.

FCC rules require noting the six largest signals even if they do not exceed the limits. These should be noted and compared with the requirements that apply to your product type (either Class A or Class B).

For conducted emissions, a relaxation in limit is allowed for signals that are broadband. To take advantage of this allowed deduction of 13 dB the signals must first be classified as narrowband or broadband. Here again digital storage modes are useful.

For example a conducted emissions display is shown (Figure 4-4). To classify signals, operate digital storage with PEAK/-AVERAGE cursor in peak mode and MAX HOLD enabled. Save this trace by activating SAVE A. With VIEW B active turn the PEAK/AVERAGE cursor control to produce an average display in the B display. To increase the effects of averaging, the sweep time may be adjusted to a slower rate than is automatically selected. This increases the number of samples averaged and will further reduce the average values resulting from averaging random or impulsive noise. As an alternative, video filtering may be activated to pro-

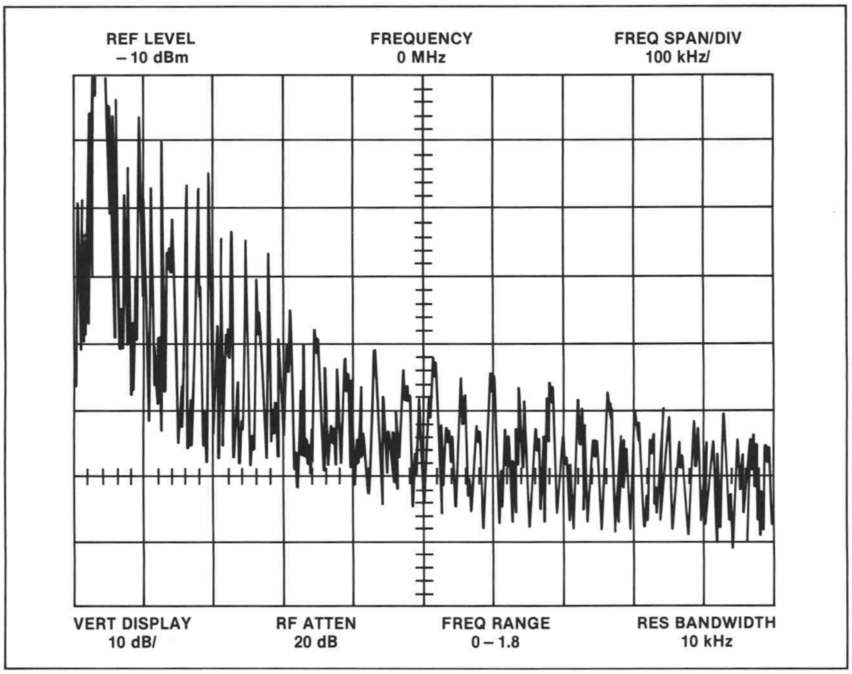


Figure 4-4. A sweep of 1 kHz to 1 MHz emissions. Sweep speed was 50 ms/div — note that many peaks are 8-9 ms apart (120 Hz repetition lines).

vide similar smoothing. As a result a display like that shown (Figure 4-5) will result. The peak readings saved in A are visibly higher than the average. However some other details are evident; some of the levels are the result of cw signals. This is a common occurrence with switching power supply or clock frequency harmonics conducted

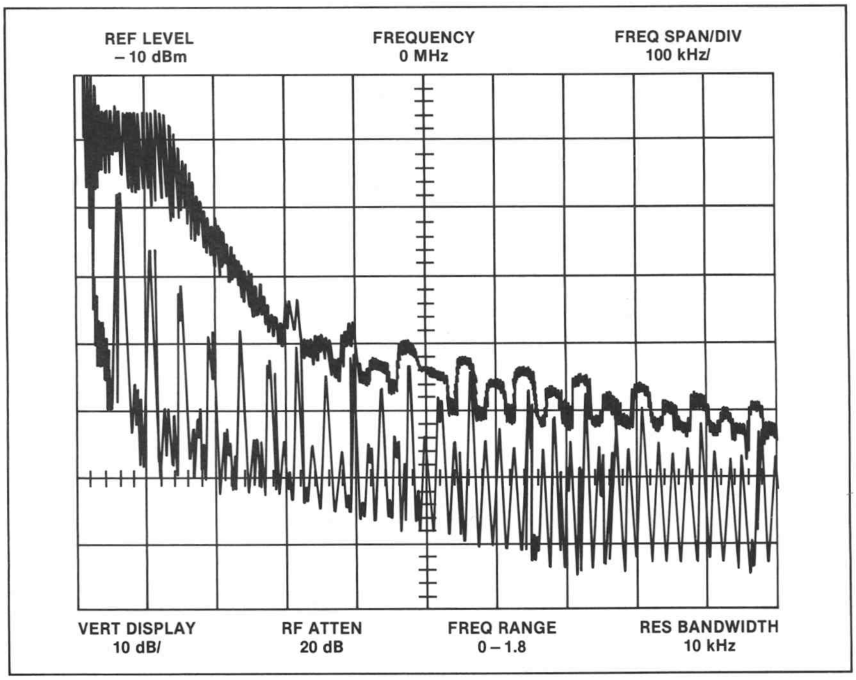


Figure 4-5. Digital storage in peak and average modes allows distinguishing broadband and narrowband emission. Sweep time is 0.5 sec to increase averaging effects.

EMI REPORT XYZ INC.

TEST ITEM: ____________ MODEL: ____________

SERIAL NO: ________ TEST NO: ________ DATE OF TEST: ________

TEST CONDUCTED PER: ____________ INPUT VOLTAGE: ________

SENSOR: ____________ TYPE OF TEST: ________

TEST METER: ________ SERIAL NO: ________ DATE OF LAST CAL: ________

OTHER INFO: ____________

Frequency in MHz	Ambient Intfer	Detector Function	Reading (Meter & Atten)	Correction Factors			Total Intfer Level	Spec Limit	Remarks
				Ant	Cable	Other			

Conducted by   Sheet   of

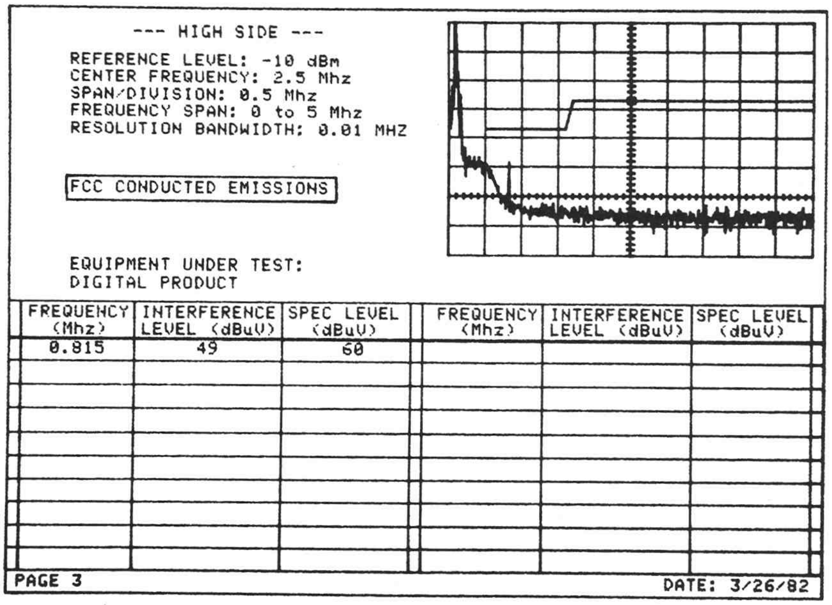
Figure 4-6. This is a typical manually filled out test report form.

to the power line. In this case the levels compared with the limit will be reduced by 13 dB for the broadband signals. Assuming the narrowband signals are below the limit values, this could spell the critical difference between meeting the FCC requirements and having to provide additional suppression of these signals.

Data should be recorded in the manner shown (Figure 4-6). If the tests are done manually this form may be used, or if the test is run automatically a form like that shown (Figure 4-7) can be produced directly from the screen of a 4052A (also 4051) using a hard copier (such as Tektronix 4611 or 4631) with the 496P under program control.

B. Radiated Emissions Tests

Radiated emissions measurements are essentially field-strength measurements made with the spectrum analyzer and an antenna as a sensor. Here, as with conducted emissions measurements, the spectrum analyzer provides rapid scanning to make changes in equipment orientation and operating mode visible over a range of frequencies. Often what is the maximum condition for one frequency may not be for another. Unlike conducted measurements that confine the signals into a coaxial cable system, radiated measurements are essentially open. The test environment must be carefully controlled because it includes the propagation path signals must take from device under test to the antenna. As disucssed in the conversion section of this application note, levels measured must be converted from spectrum analyzer display units to field strength (μVolts/meter) for comparison with legal limits.


--- HIGH SIDE ---

REFERENCE LEVEL: -10 dBm
CENTER FREQUENCY: 2.5 Mhz
SPAN/DIVISION: 0.5 Mhz
FREQUENCY SPAN: 0 to 5 Mhz
RESOLUTION BANDWIDTH: 0.01 MHZ

FCC CONDUCTED EMISSIONS

EQUIPMENT UNDER TEST:
DIGITAL PRODUCT

FREQUENCY (Mhz)	INTERFERENCE LEVEL (dBuV)	SPEC LEVEL (dBuV)	FREQUENCY (Mhz)	INTERFERENCE LEVEL (dBuV)	SPEC LEVEL (dBuV)
0.815	49	60			

PAGE 3 DATE: 3/26/82

Figure 4-7. Automated measurements and test report.

Maximizing the device under test is more complicated for radiated tests than for conducted tests. Following the guidelines of FCC Part 15 Subpart J, involves using a carefully controlled test environment. At this writing a Docket, 21731, defines the test site (as shown in Figure 4-8). The details of the site are (at this writing) under discussion. The purpose of the site is to minimize reflections. The path the emissions must traverse is intended to be free of obstruction and the antenna is presumed to experience up to 4.7 dB of additional signal due to ground reflection (6 dB corresponds to a perfectly reflecting ground).

The spectrum analyzer aids maximizing with wide sweeping measurements and convenient display memory. Also, peak detection allows fast sweeping. While a quasi-peak detector has the detector properties recommended by the FCC, the long detector time constant requires slow frequency changes. To avoid missing an infrequently occurring signal the receiver or spectrum analyzer would have to dwell on a particular frequency for some time, and then step no more than a filter width in frequency to avoid missing signals. The spectrum analyzer without the quasi-peak will be able to scan a range of frequencies at optimum speed (this is selected automatically in the 492, 492P, 496, and 496P) without skipping frequencies or sweeping too fast for the resolution bandwidth. The MAX HOLD mode of digital storage allows repetitive scans to accumulate the highest level. This prevents missing an infrequent or slowly changing signal level.

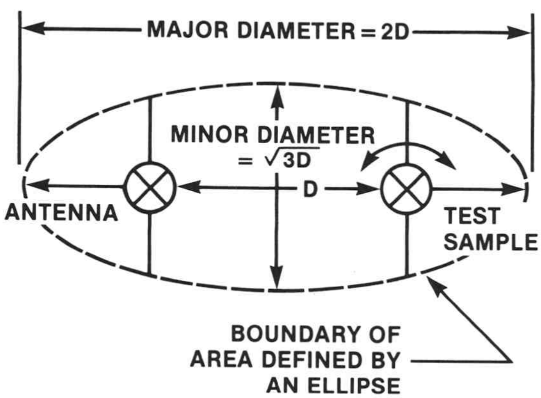


Figure 4-8. This schematically shows the area that must be kept free of reflections for radiated EMI measurements.

MAX HOLD helps when adjusting antenna height and equipment orientation to obtain maximums. Then by saving this maximum, test personnel can return to a maximum at a particular frequency by enabling VIEW B and comparing the readings (Figure 4-9). For FCC limits, the resolution bandwidth should be set to no less than 100 kHz (the Tektronix 490 Series of analyzers is ideally suited to this by having a 100 kHz bandwidth setting available). As with conducted emissions the six highest readings should be recorded in the test record. Equipment orientation should be noted to allow repeating the test precisely when the effects of design changes need to be verified for their effect on the EMI profile of the product.

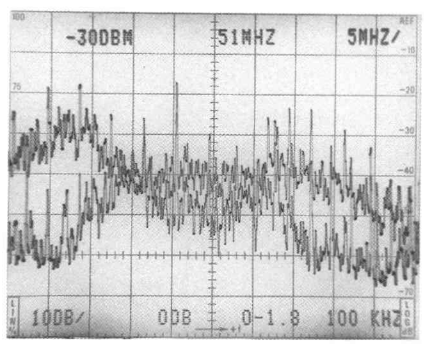


Figure 4-9. Using MAX HOLD and finally SAVE A accumulates the maximum levels and "freezes" it. VIEW B - lower trace shows the levels at the final equipment orientation. With this display, it is possible to return to a maximum for a particular frequency or range of frequencies.

C. FCC Limits and Examples

For convenience the limits are given both as stated in the rules and after conversion to other units (Table 1). Conversion to dBm for radiated measurements must include an antenna factor. For conducted measurements the conversion is more straightforward. Note that spectrum analyzer measurements will be peak rather than quasi-peak. In some circumstances the quasi-peak detector will give significantly lower readings. However (at this writing) conversion or correlation between peak and quasi-peak is not permitted. Since quasi-peak readings will always be lower than peak, passing with peak readings will provide additional assurance of compliance. If this is not possible or desirable, testing at those frequencies with a quasi-peak equipped receiver will be unavoidable. If such testing is done it will be desirable to get comparative readings between the spectrum analyzer and receiver as a means of correlating measurements. This will allow minimizing the use of test facilities using the receiver except to provide formal test data. The method of correlating peak and quasi-peak readings is given in a later section.

To use this table make the measurements using the methods given previously. For example suppose the display shown (Figure 4-10) was obtained. Since this is a test of radiated emissions take the measured level (– 79 dBm) and add the antenna (approximately 26 dB for a tuned dipole) factor to it. Add the conversion factor to convert to dBμV/m. The result is 54 dBμV/m. This level is 8 dB above the limit (46 dBμV/m) and should be recorded.

CLASS A LIMITS			
Conducted	**Spec Limit**	**dBμV**	**dBm**
0.45 to 1.6	1000 μV	60	– 47
1.6 to 30 MHz	3000 μV	69.5	– 37.4
Radiated @ 30 meters			
30 to 88	30 μV/m	29.5 dBμV/m	– 77.46 + K
88 to 216	50 μV/m	33.98 dBμV/m	– 73.02 + K
216 to 1000	70 μV/m	36 dBμV/m	– 71 + K
CLASS B LIMITS			
Conducted			
0.45 to 30 MHz	250 μV	47.96	– 59.0412
Radiated @ 3 meters			
30 to 88	100 μV/m	40 dBμV/m	– 67 + K
88 to 216	150 μV/m	43.52 dBμV/m	– 63.48 + K
216 to 1000	200 μV/m	46.02 dBμV/m	– 60.98 + K

K is antenna factor

Table 1. FCC Part 15 Subpart J limits conversions.

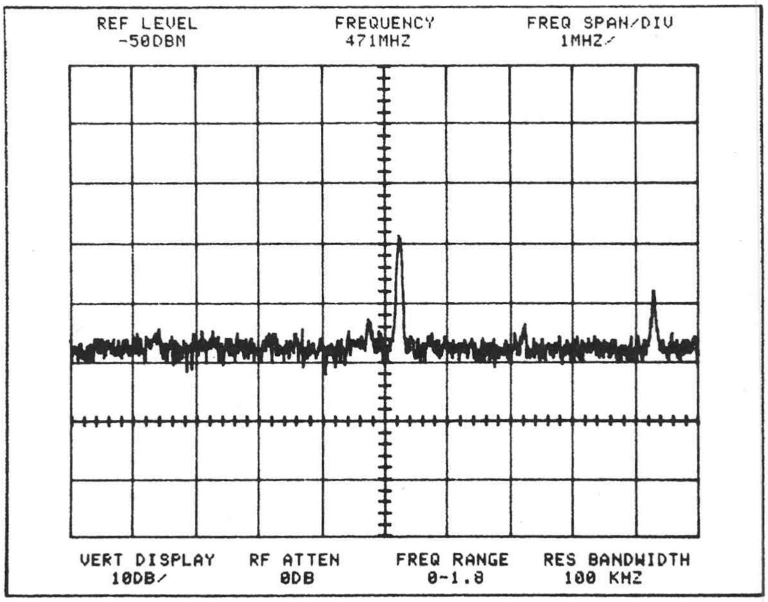


Figure 4-10. Radiated signal at 471 MHz - 79 dBm.

D. Antenna Selection and Distance for Measurements

In the previous table the limit values did not include antenna factor. The graph (Figure 4-11) does, suggesting that for Class A equipment the received voltage, assuming an isotropic antenna, will be below the sensitivity limit of the spectrum analyzer. When the device under test is less than 1 meter cubic volume the FCC recommends testing at a distance of 3 meters. This will add 20 dB to measurements.

As shown (Figure 4-11) the level varies with frequency even for an idealized isotropic antenna. This is due to the distance in wavelengths changing with frequency (wavelength is inversely proportional to frequency). To add more than 2.15 dB of gain, (this is the gain of the tuned dipole over the isotropic) use a log periodic antenna. These are obtainable from several manufacturers and come with antenna correction factor plots versus frequency. The advantages of the log periodic are: broad frequency coverage, directivity, and hence gain. The directivity can have an added advantage in performing radiated tests in the presence of high ambient levels resulting from nearby broadcast stations. If possible, the test site could be oriented to permit placing antenna with the broadcast station toward the back of the antenna gain pattern.

FCC Part 15 (and VDE and CISPR) favors the use of linearly polarized antennas — such as a tuned dipole, or log periodic. Certain other tests, such as MIL-STD 461 allow a circularly polarized antenna (e.g. log spiral). Linearly polarized antenna respond best to electromagnetic field whose electrostatic (E) and electromagnetic (H) fields always reside in one plane (vertical or horizontal for example). A circular antenna is 3 dB less sensitive to plane polarized waves. It may be much less sensitive (20 or 30 dB or more) to waves that are polarized circularly but the wrong sense (right hand versus left hand).

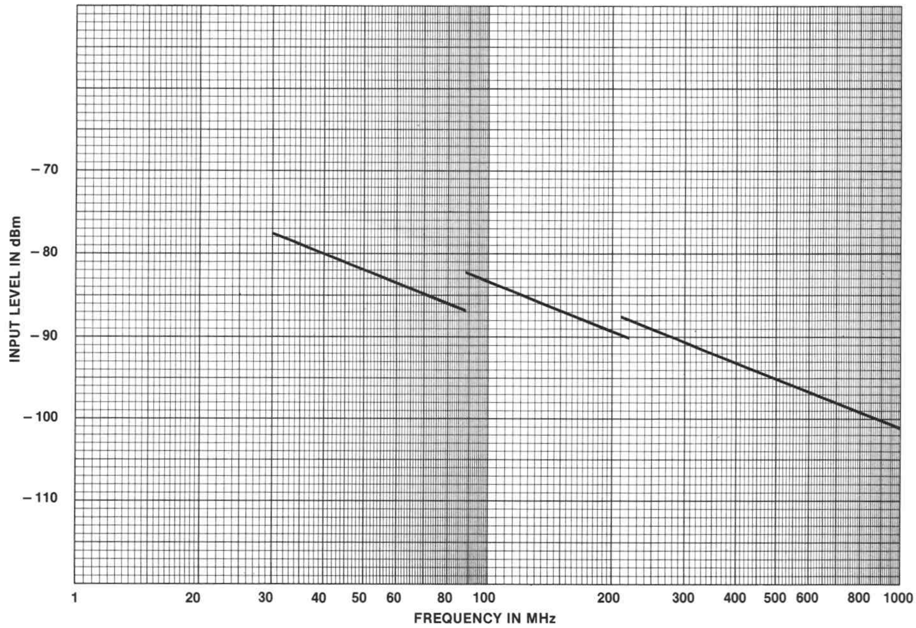


Figure 4-11. Input voltage — for FCC Class A — unity power gain antenna.

E. Testing in the Presence of Ambient Signals

In addition to the use of directional antenna, EMI measurements can be facilitated with the use of the spectrum analyzer and its ability to show fine details of the ambient signal. Most prominent in the frequency range of interest are television broadcast signals.

These are very broadband signals. Unless the EMI lies precisely on top of a carrier frequency it is unlikely to coincide with a major long term source of signals. With the ability to switch the digital storage off, the peak levels from the computing device can be seen against the video modulation in the background (as shown in Figure 4-12).

In rare cases where narrowband signals nearby conflict with tests, it may be necessary to test at hours when signals are less numerous.

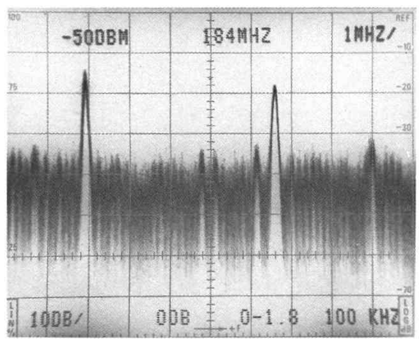


Figure 4-12. Observing the signal with digital storage off reveals a repetition pattern not likely to be part of this TV signal (Channel 8).

V. Testing for VDE and CISPR Requirements

Test data from manufacturers is not acceptable to meet VDE or CISPR. Unlike the FCC in the U.S. which will accept test data for certification, manufacturers' testing provides assurance that a test station will not discover EMI levels above limits. Formal testing by a test station is, in effect, an independent audit of the quality of the product. For example VDE evaluates the product for all safety hazards. In this sense the test

is similar to meeting the requirements of U.L. approval in the U.S. This is an apt comparison since the testing done includes all hazards including any posed to vital communications by EMI.

There are many classes of VDE and CISPR requirements. Some are designed for industrial and scientific equipment. Others include consumer appliances, such as hand tools that are electrically driven. For computing devices there are three limit classes of VDE 0871. Classes A and C, while relaxed by 12 dB from the Class B limits, are specialized. The Class C limits apply on a site by site basis, and Class A requires equipment be tagged and notification be given when moved. The Class B limit, when met, provides the greatest protection for communications services and the greatest freedom for the user. Products which meet this testing can be broadly marketed and freely moved about. This means fewer restrictions on the seller and the buyer of such products.

Although much of this discussion centers on VDE 0871 it will relate to CISPR requirements as well. The VDE requirements follow the CISPR recommendations as do those of many other countries. For additional information on the requirements, consult the rules for the appropriate country. Although most follow CISPR, some variations in mandatory versus voluntary limits may exist. In any case, CISPR recommendations are evolving and are revised to reflect new needs for protecting users of the electromagnetic spectrum from disruptions caused by EMI.

A. Limit Tolerances

The VDE limits are applied to testing in a way that allows for variability in testing and equipment performance. When testing is done on an individual product, its measured EMI levels must fall 2 dB or more below the limit. Equipment, subsequently retested, will be considered out of limit if its measured levels exceed limits by 2 dB or more.

For equipment tested in lots, statistical techniques are used to assure that 80% of the units tested have 80% confidence of being below the limits.

B. Conducted Emissions Tests and Limits

The test limits required to comply with 0871 Class B are shown (Figure 5-1). As with U.S. limits, the testing is performed with a LISN. Above 150 kHz a different LISN is used having an impedance of 150 ohms (Figure 5-2). As a result the spectrum analyzer input impedance is only one-third of the total load. Hence any values measured should be adjusted up by the ratio of 3 (9.5 dB) to correlate to the voltage imposed on the total 150 ohm impedance.

During the tests all the normal precautions against front-end overload should be applied. The procedure followed should be like that given in the FCC testing section. Additionally levels can be adjusted to correlate to the quasi-peak detector defined by CISPR if the pulse repetition rate can be determined. The suggested procedure is:

- Be careful of overload (particularly at the low frequency 10 kHz limit).

CONDUCTED — VDE CLASS B LIMITS

Frequency Range	Recommended Bandwidth	Level	Recommended Sensor/Antenna	Limit (dBm)
10 kHz to 150 kHz	200 Hz	79 dBμV at 10 kHz to 57.5 dBμV at 150 kHz	150Ω LISN or 50Ω LISN	−28 −49.5
150 kHz to 500 kHz	9 kHz	54.0 dBμV	150Ω LISN	−53
500 kHz to to 30 MHz	9 kHz	48 dBμV	150Ω LISN	−59

Figure 5-1. VDE conducted emissions limits.

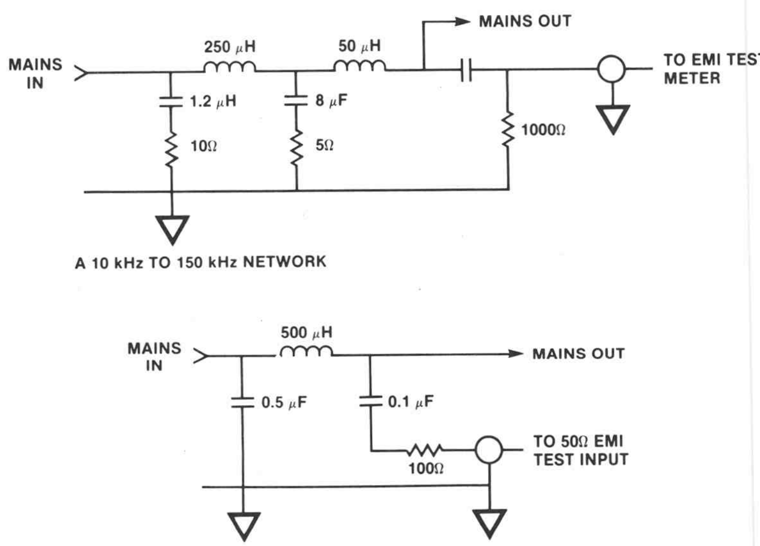


Figure 5-2. LISN — or mains networks for conducted EMI measurements.

- To make certain that the frequency range examined goes down to 10 kHz use the zero frequency marker. On the 496 this signal will appear at the full screen deflection regardless of RF attenuation and will be present with the RF input disconnected. To make sure that the analyzer is covering a low enough range, position the zero frequency marker (Figure 5-3) as shown. This procedure can also be used with the 492 but requires using MIN Distortion mode and an external 10 dB attenuator to protect the mixer from overload.
- Make the measurement with a resolution bandwidth of 100 Hz (or 1 kHz) if preferred to maintain a more rapid sweep. Use wider and narrower resolution bandwidths to determine if emissions are broadband or narrow. Measurements should be recorded and the bandwidth noted for later correction to the recommended bandwidth.

A typical sweep of the frequency range is shown (Figure 5-4) to contain narrowband emissions as well as broadband. In this example the conducted level (in a 1 kHz bandwidth) for narrowband signals is a maximum of -28 dBm over the frequency range. The narrowband signal is converted to the units of the specification by

$$-28 \text{ dBm} + 107 = 79 \text{ dB}\mu\text{V}$$

The broadband peak (-26 dBm at 14 kHz) must first be converted to the bandwidth of the test limits by adjusting for bandwidth.

$$\text{Bandwidth adjustment} = 20 \log \left(\frac{B_1}{B_2}\right) = 20 \log \left(\frac{200}{1000}\right) = -14 \text{ dB}$$

Since the bandwidth was not 200 Hz, the level is corrected by 14 dB. The measured level is adjusted to -40 dBm or 67 dBμV - 9 dB below the limit.

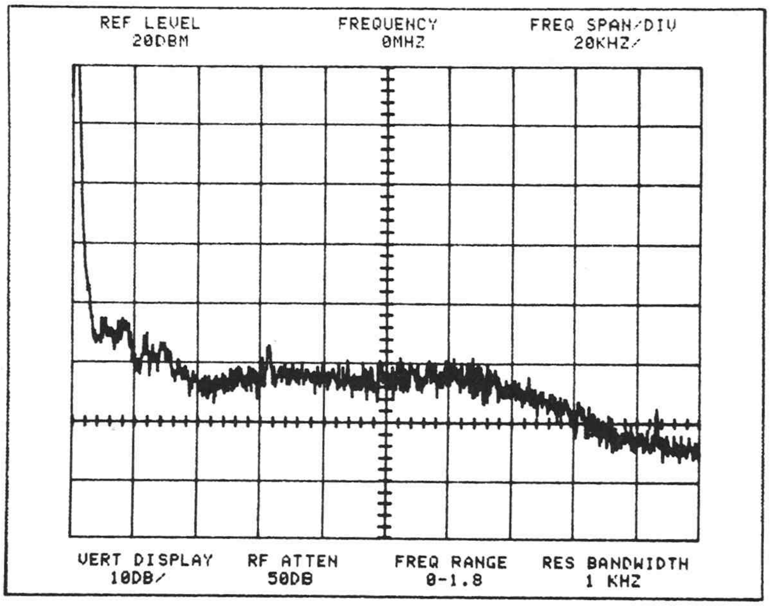


Figure 5-3. The zero frequency signal can be used to align center frequency and span/division.

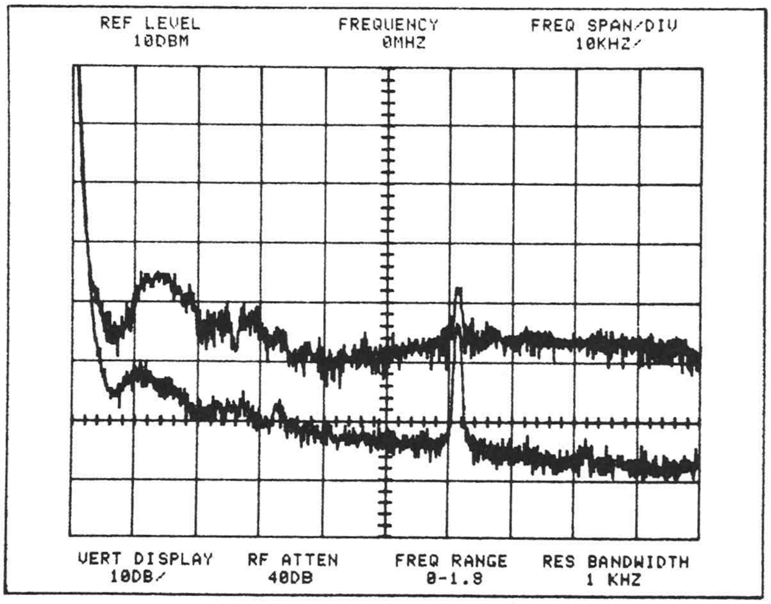


Figure 5-4. Typical sweep of 0 to 100 kHz range. Top trace is MAX HOLD. Lower is average. Note zero mark at left edge.

C. Radiated Tests

Limits for 0871 Class B are given in the table (Figure 5-5). Bandwidths suggested for use with the 496 and 496P are 10 kHz and 100 kHz over the ranges of 150 kHz to 30 MHz and from 30 MHz to 1 GHz respectively. As with conducted emissions tests the 1 kHz or 100 Hz bandwidth may be used in the lowest, 10 kHz to 150 kHz range. Tests may be performed at closer than 30 meters provided a magnetic loop antenna is used and the measurements corrected for distance. Linearly polarized antennas are used. To help reduce the effects of ambient signals and provide greater overall sensitivity a directional antenna may be used above a few hundred megahertz.

D. Correlation of Peak to Quasi-peak

Formal testing will be done independently of the manufacturer to determine compliance. This testing will be performed with equipment having the standard CISPR quasi-peak detector and bandwidths. The measurements made with a spectrum analyzer will be peak readings. To convert from one to the other requires knowing the spectrum analyzer impulse (or 6 dB) bandwidth and the pulse repetition rate.

Correlation from peak to quasi-peak proceeds in a series of steps:

- Determine whether the emission is broad or narrowband. If it is broadband, correlation will have to be made.
- If the emission is narrowband the spectrum analyzer reading will be the same as that of a receiver with a quasi-peak detector.
- For the broadband emission determine the pulse repetition rate.
- Read from the graph, the correction in dB for the CISPR resolution bandwidth.

RADIATED — VDE CLASS B LIMITS

Frequency Range	Recommended Bandwidth	Level	Recommended Sensor/Antenna
10 kHz to 150 kHz	200 Hz	50 μV/m at 30 m	Magnetic loop 60 cm per side maximum
150 kHz to 30 MHz	9 kHz	50 μV/m at 30 m	Magnetic loop as above or 1 meter vertical rod
30 MHz to 470 MHz	120 kHz	50 μV/m at 10 m	Balanced dipole tuned to 80 MHz or higher, 1 to 4 meter height above reference plane
470 MHz to 1 GHz	120 kHz	200 μV/m at 10 m	Balanced dipole — plane polarized; Directional — plane polarized antennas may be used

Figure 5-5. VDE radiated emissions limits.

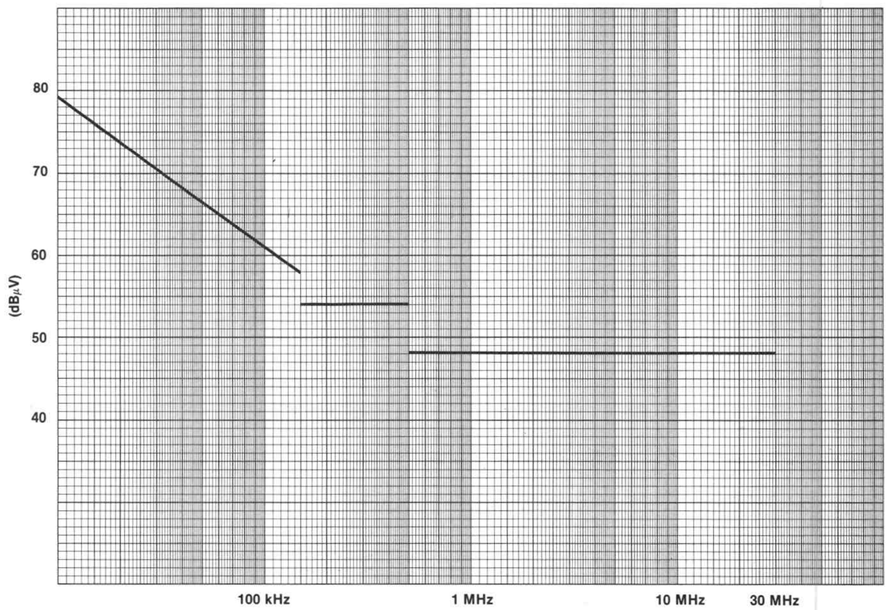


Figure 5-6. VDE 0871-B conducted limits in dBμV.

- Subtract the correction factor from the peak (spectrum analyzer) reading.
- Add the bandwidth correction factor to express the measurement in terms of the specified test bandwidth.

The pulse repetition rate can be determined in several ways:

- Place the spectrum analyzer in the zero span mode and view the detected signal in the time domain. This can be accomplished easily by a 492, 492P, 496, or 496P by rotating the SPAN control counterclockwise.
- With the spectrum analyzer in normal frequency domain display, observe the effect of changing the time per division setting. The density of lines displayed should decrease as sweep time is decreased. At a convenient time per division the repetition lines will not only be visible but measurable.
- If the pulse occurs irregularly an average rate can be determined. This can be done directly from measuring the time interval for several rep rate lines. Or another method may be used. Note the emission level in peak mode of digital storage. Note the emission level in the average mode. The repetition rate is calculated by the equation

$$P_{RR} = B_{imp}\left(\frac{V_{AV}}{V_{peak}}\right)$$

B_{imp} = impulse bandwidth, or 6 dB bandwidth as an approximation.

Once the repetition rate is known the graph (Figure 5-7) can be used to determine the correction to calculate quasi-peak. This new value will also have to be adjusted for the difference in bandwidth. For example if the spectrum analyzer bandwidth — measured at 6 dB bandwidth — is narrower than the specified bandwidth (120 kHz above 30 MHz for example) the quasi-peak receiver reading will be higher by the bandwidth factor.

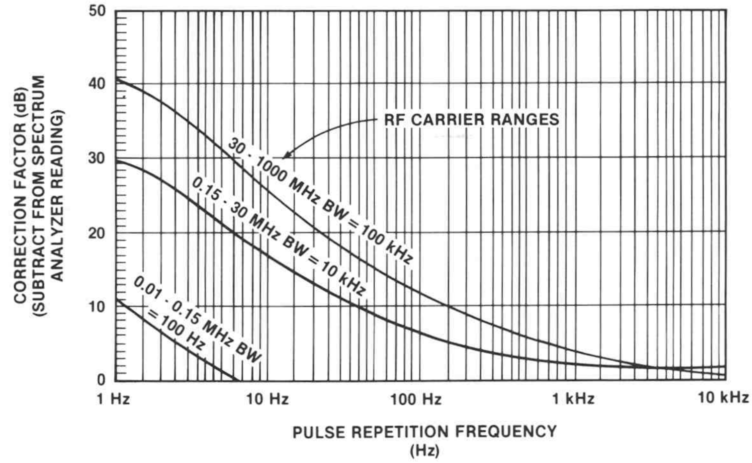


Figure 5-7. Peak to quasi-peak conversion.

VI. Open Site Measurements

Radiated emissions tests must be performed using some type of test site. Unless an anechoic chamber with very effective shielding is used the site is open for outside signals to enter and confuse the test operator. Surveying potential site locations or checking the level of activity prior to testing can be done with a spectrum analyzer.

To perform tests that are even roughly correlatable among different sites requires that the propagation path be predictable between the device under test and the test antenna. To assure this is the case, in the U.S. the FCC requires a measurement of site attenuation to compare the site with a theoretical model.

Although site attenuation can be measured with a signal generator and spectrum analyzer, a tracking generator useful for other swept RF measurements can be very useful.

A. Measuring Site Ambient Levels

In an open site, signals other than those emanating from the device under test are free to enter. It is in surveying the ambient levels that the operator discovers what a busy place the electromagnetic spectrum is.

Although some users, broadcast stations for example, are transmitting continuously, many others transmit only when the need arises, as with aircraft communications for example. Still others will occur very infrequently and may be very close by (police or ambulance communications for example).

The spectrum analyzer with MAX HOLD mode in digital storage can capture even the most infrequent signal if left on long enough to capture the event. For as long as the spectrum analyzer is left on in

MAX HOLD any signal above the peak noise level will leave a perceptible peak in the display. As an example, the trace shown (Figure 6-1) shows the result of sweeping the 30 to 500 MHz frequency range. MAX HOLD eliminates the need to view the display continuously for many hours.

B. Site Attenuation Measurements

Except for reflections from the ground along the propagation path, the test area should be free from reflections. Such reflections could cause deep nuls in frequency response of the site or unexpectedly large variations in signal levels with changes in equipment orientation. While reflections can add up to 6 dB of reinforcement in one case, they can also lead to deep nuls usually dependent on antenna height (distance is assumed fixed) and equipment orientation. These constraints on the test site are aimed at permitting repeatable tests at various sites. The site attenuation plot required by the FCC measures actual attenuation over the site path and compares it to a theoretical model. This model is essentially a free space path modified for the ground reflection assumed to be a contributor of 4.7 dB (perfectly reflecting ground would contribute 6 dB).

The equation for this model is:

$$A(dB) = 20\log(d) + 20\log(f) - G(sending) - G(receiving) - 32.3$$

In this case d is the test distance typically 3, 10 or 30 meters; f is the frequency in MHz; G(sending) is the gain (in dB) of the transmitting antenna over an isotropic radiator; G(receiving) is the gain (in dB) of the receiving antenna over an isotropic radiator.

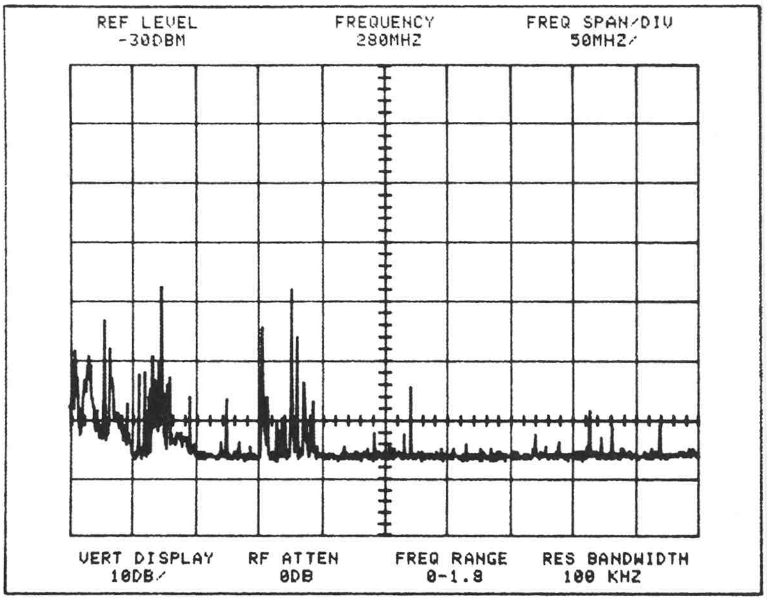


Figure 6-1. A wide view of the 30 MHz to 530 MHz range shows a number of strong signals — most are FM and TV broadcast.

The measurement employs a signal source with an adjustable attenuator both for sending signals from the transmitting antenna and as a substitution for the receiving antenna voltage. The signal source is first attached to the transmitting antenna and its output raised until a signal is observed above the noise level. Then the signal generator is disconnected from the transmitting antenna and connected to the spectrum analyzer. The attenuator is adjusted until the spectrum analyzer reading is identical to the antenna voltage. The additional attenuation is then recorded as the site attenuation at that frequency. From 30 MHz to 300 MHz a measurement is required every 25 MHz. From 300 MHz to 1000 MHz a measurement is taken every 50 MHz.

Although this technique can be readily followed using the spectrum analyzer with a conventional signal generator another method is faster.

A tracking generator compatible with the 490 Series analyzers (TR 503) or 7L12, 13, or 14 (TR 502) may be used as the signal source. Using its attenuator the substitution can be made for attenuation levels of 0 to 60 dB.

The suggested arrangement of equipment is shown (Figure 6-2). Here also digital storage helps with the measurement. So long as the frequency range swept is within the limits of the antennas for their tuning range the readings will provide a measurement of site attenuation. Also using MAX HOLD can allow adjustment and capturing the data over a wide range of frequencies quickly (Figure 6-3).

A plot of the theoretical curve (Figure 6-4) shows that for isotropic radiating and receiving antennas the limit of attenuation is under 60 dB, within the range of the tracking generator. Using tuned dipoles, MAX HOLD may be used to capture the maximum response and display the result. The received RF level may then be stored using SAVE A and when the tracking generator is connected directly (through the cable) the difference in levels read directly as the value of site attenuation.

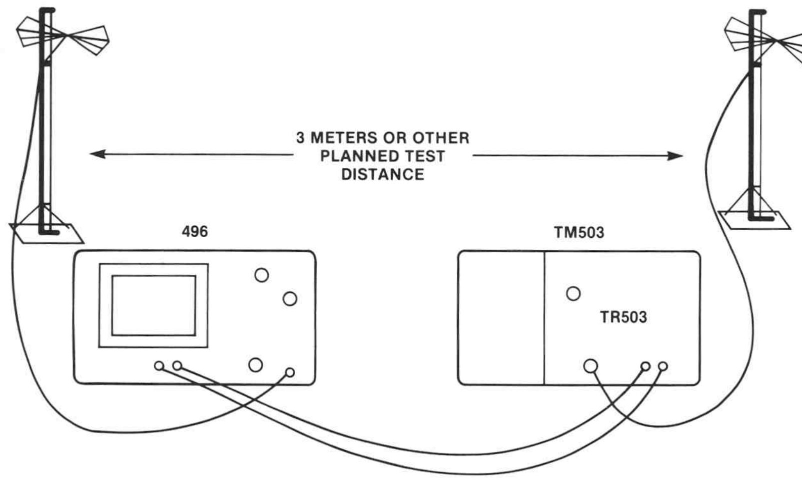


Figure 6-2. Measuring site attenuation requires a pair of antennas, signal source (TR503 for example) and sensitive RF voltage measuring device (a spectrum analyzer provides frequency selectivity and ability to display any ambient signals that could disrupt the measurement).

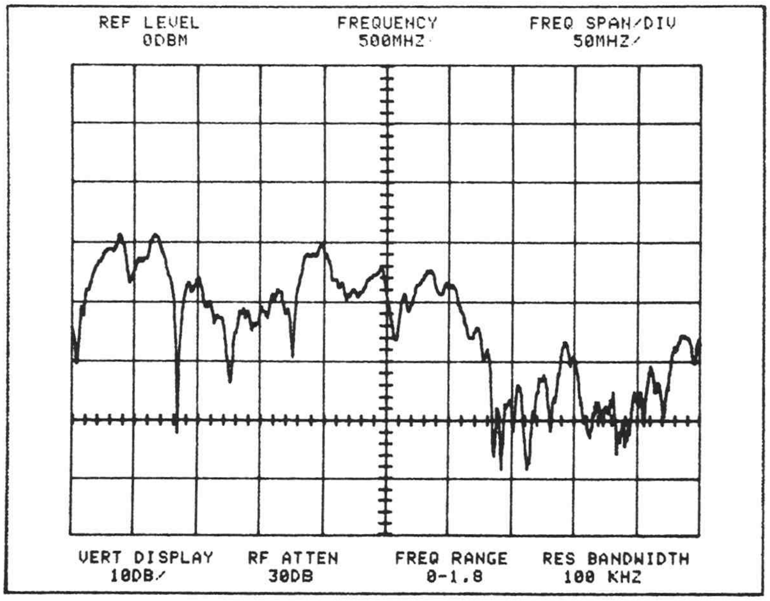


Figure 6-3. Using MAX HOLD allows swept rather than point-by-point measurements of attenuation. You can detect deviation from theoretical without missing frequencies.

VII. Automated Measurements

This automatic calibration program aids the operator in performing front panel amplitude calibration of a 492P or 496P. The program operates the controls of the spectrum analyzer making calibration easier and quicker.

A detailed description of the program follows. Although written in the enhanced BASIC of the Tektronix 4041 Computer Controller it can be converted to other controllers, such as the Tektronix 4051,4052A, or 4054A with ease.

Line 100 — Is the main entry point. It defines the spectrum analyzer address, model number and options as integers.

Line 110 — Establishes the 4041 thermal printer as the output device for the printed instructions.

Lines 130 to 140 — Instructions are printed.

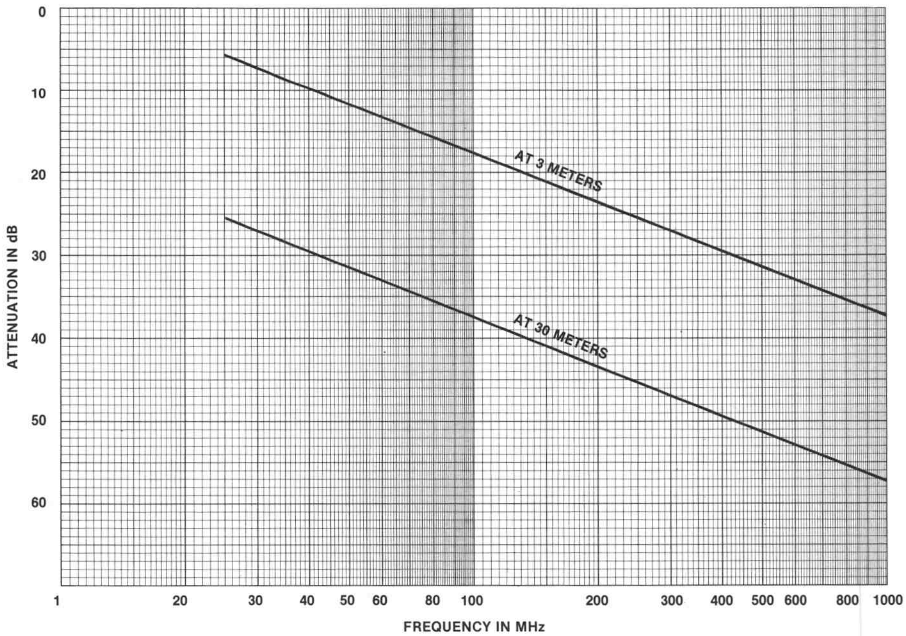


Figure 6-4. Ideal site attenuation versus frequency.

Lines 150 to 180 — Gets the GPIB address of the spectrum analyzer from the operator. If out of range the operator is asked to re-try the entry.

Lines 190 to 250 — Reads the spectrum analyzer ID message consisting of model, codes and formats level, firmware level, and options. An interrupt handling procedure is set up for responding to service request (SRQ) interrupts.

Line 220 — Reads the current spectrum analyzer settings so that they may be restored when calibration is completed.

Lines 260 to 310 — This is the interrupt handling subroutine. If another address is causing the interrupt polling continues until the analyzer is polled. Error messages for the analyzer are printed. This clears the interrupt condition.

Lines 320 to 610 — Include the main calibration steps.

Lines 630 to 650 — Restore the analyzer to its original settings and remove it from the IEEE Std-488 bus.

```
 100 Autocal:     integer model,opt,z9 ! DEFINE INTEGER VARIABLES
 110     Open #40:"PRINT:" ! DEFINE THE PRINTER AS DEVICE #40
 120     Dim instr$ to 180,setting$ to 400 ! SET UP STRINGS FOR INTRUCTIO
N &      SETTINGS
 130     Instr$="CONNECT THE CALIBRATOR OUTPUT TO THE SPECTRUM ANALYZER R
F INPUT WITH A LOW LOSS CABLE  THE CAL SIGNAL IS 100MHZ AT -20DBM REFERENC
ED TO 50 OHMS"
 140     Print #40:instr$ ! PRINT OUT ON THERMAL PRINTER
 150 Getadr:     input prompt "49XP ADDRESS= ";z9 ! ASK FOR ADDRESS
 160     If (z9<0) or (z9>30) then goto errstart else goto rdid
 170 Errstart:     print "ADDRESS OUT OF LIMITS" ! OPERATOR WARNING
 180     Goto getadr ! TRY AGAIN TO GET OPERATOR TO GIVE CORRECT ADDRESS
 190 Rdid:   ! THIS SECTION READS THE INSTRUMENT ID
 200     Input prompt "ID?" deln "," #z9:model,code,opt,firm ! GET ID
 210     Print "YOUR ";model;"P";" OPT";opt;" IS ON LINE" ! VERIFY MODEL
 220     Input prompt "SET?" #z9:setting$ !READ ALL THE SETTINGS
 230     On srq then gosub srq49x ! ARM THE INTERRUPT HANDLER
 240     Enable srq !ENABLE SERVICE INTERRUPTS
 250     Goto autocl ! GOTO MAIN AUTOCALIBRATION SECTION NOW
 260 Srq49x:   !SRQ HANDLER FOR 49XP
 270     Poll status,addrs ! READ THE STATUS AND ADDRESS OF THE DEVICE
 280     If addrs<>z9 then goto srq49x ! IF NOT 49X POLL UNTIL IT IS
 290     Input #z9 prompt "ERR?":ercode$ ! READ ERROR CODES
 300     Print ercode$ !PRINT FOR DIAGNOSTIC PURPOSES
 310     Resume ! RETURN TO THE PROGRAM
 320 Autocl:     print "AUTOCAL IN PROGRESS"
 330   ! THE REMAINDER OF THE MESSAGES WILL BE PLACED ON THE 49XP SCREEN
 340     Print #z9:"INIT" !INITIALIZE THE SPECTRUM ANALYZER
 350     Print #z9:"SPA 20K;VRTDSP LOG:2" ! 2DB/DIV VERT 20KHZ/DIV HORIZ
 360     Print #z9:"RDOUT 'SET DOT ON CENTER LINE WITH HORZ'"
 370     Print #z9:"RDOUT 'POSITION, THEN PRESS PROCEED'"
 380     Input a$ ! WAIT FOR OPERATOR ADJUSTMENT
 390     Print #z9:"RDOUT 'SET TRACE ON BOTTOM LINE WITH'"
 400     Print #z9:"RDOUT 'VERT POSITION,THEN PRESS PROCEED'"
 410     Input a$ !WAIT FOR OPERATOR ADJUSTMENT
 420     Print #z9:"RDO NORMAL;CLIP ON" !TURN ON READOUT AND CLIPING
 430     Print #z9:"SPAN 1M;FREQ 100M;DEGAUS;SIG;REFL -10;VRTD LOG:10;SIG
;WAI"
 440     Print #z9:"FIBIG 100;CEN;SIG;WAI;REP 2" ! CENTER ON 100MHZ SIG
 450     Print #z9:"FRCAL 100M" ! SET READOUT TO 100MHZ
 460     Print #z9:"SPAN  200K;SIG;WAI;FIBIG 100;CEN" ! NARROW THE SPAN
 470     Print #z9:"SPA 20K;SIG;WAI;FIBIG 100;CEN;REF -20;TRIG FRERUN"
 480     Print #z9:"RDOUT 'SET PEAK TO TOP GRATICULE LINE'"
 490     Print #z9:"RDOUT 'WITH LOG CAL. THEN PRESS PROCEED'"
 500     Input a$ !WAIT FOR OPERATOR TO FINISH
 510     Print #z9:"RDOUT 'SET TRACE PEAKS = WITH AMPL'"
 520     Print #z9:"RDOUT 'CAL,THEN PRESS PROCEED'" !ALTERNATE 10&2DB/DIV

 530     Print #z9:"VRT LOG:10;SIG;WAI;VRT LOG:2;SIG;WAI;REP 1E6"
 540     Input a$ ! WAIT UNTIL OPERATOR IS READY
 550     Wbyte #z9:dcl ! CLEAR ALTERNATING DISPLAY BEFORE 1E6 TIMES
 560     Print #z9:"RDOUT 'SET TRACE PEAK TO TOP LINE WITH'"
 570     Print #z9:"RDOUT 'LOG CAL, THEN PRESS PROCEED'"
 580     Print #z9:"TRIG FRERUN"
 590     Input a$ ! OPERATOR DONE?
 600     Print #z9:"RDOUT 'FRONT PANEL CALL COMPLETED'"
 610     Print #z9:"RDOUT ' PRESS PROCEED'"
 620     Input a$ !OPERATOR WAIT
 630     Print #z9:setting$ !RESTORE ORIGINAL SETTINGS
 640     Wbyte gtl(z9) ! RESTORE FRONT PANEL CONTROL
 650     Wbyte atn(63) ! UNLISTEN TAKE IT OFF THE BUS
 660     End
*
```

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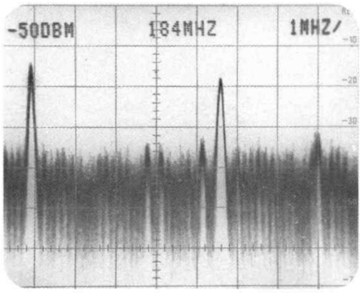
Digital storage is disabled to show low level EMI



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